VOL. 250 JULY 1952 No. 7

American Journal of Science

Established in 1818 by Benjamin Silliman

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Published monthly. Eight dollars a year. Seventy-five cents a copy.
Foreign, eight dollars sixty cents. Canada, eight dollars thirty-five cents.

AMERICAN JOURNAL OF SCIENCE

Established in 1818 by Benjamin Silliman

THE FIRST SCIENTIFIC JOURNAL IN THE UNITED STATES

DEVOTED TO THE GEOLOGICAL SCIENCES AND TO RELATED FIELDS

Editor: CHESTER RAY LONGWELL
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Entered as second-class matter at the Post Office at New Haven, Conn., under the Act of March 3, 1879. Published monthly at Sterling Tower, Yale University, New Haven, Conn.

Subscription rate $8 per year (75 cents a number). Student rate $5 per year (application blanks available on request). Postage prepaid to the United States and Central and South America; 35 cents per year to Canada; 60 cents per year elsewhere.

The JOURNAL completed its *first* series of 50 volumes in 1845, its *second* series of 50 volumes in 1870, its *third* series of 50 volumes in 1895, its *fourth* series of 50 volumes in 1920, its *fifth* series of 36 volumes in 1938. Since 1938 the numbering by series has been discontinued, and volumes are annual and bear the whole numbers as of 1818, that for 1939 being volume 237.

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REFERENCE

Lane, B. H., 1935. Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C., 25c.)

[American Journal of Science, Vol. 250, July, 1952, Pp. 481-497]

American Journal of Science

JULY 1952

SUBMARINE GEOLOGY OF TWO FLAT-TOPPED NORTHEAST PACIFIC SEAMOUNTS

ALFRED J. CARSOLA AND ROBERT S. DIETZ

ABSTRACT. Erben and Fieberling Guyots lie about 800 and 600 miles, respectively, west of San Diego, California. Their tops are largely rocky. The sparse deposits consist of a thin patchy veneer of calcareous and siliceous organic remains and small amounts of clastic mineral grains and basalt fragments derived from the underlying rocks. The rocks of Erben Guyot are encrusted with manganese dioxide. Geomorphic and petrologic evidence indicate the seamounts to be extinct basaltic volcanoes.

The drowned summit platforms of Erben Guyot (400 fathoms) and Fieberling Guyot (280 fathoms) are considered to be planes of marine abrasion cut by wave action within a few fathoms of sea level. Possible explanations are discussed for the present deeply drowned position of these truncated surfaces. It is concluded that these extinct submarine volcanoes constitute an uncompensated load on the earth's crust of such magnitude that they tend to subside slowly because of yielding of the earth's crust.

Foraminifera of Miocene age have been identified in the calcareous cement of a breccia from the Erben Guyot surface. Thus, this guyot appears to have been truncated in Miocene or earlier time.

INTRODUCTION

THE two seamounts described in this paper lie close to the great circle route from San Diego to Hawaii (fig. 1). The U. S. Navy Hydrographic Office Chart No. 0527 shows Erben Bank at 32° 50′ N and 132° 32′ W which is about 800 nautical miles west of San Diego, California. A sounding of 244 fathoms marks the summit of this seamount. This isolated feature was discovered in 1874 by the *USS Tuscarora* and the seamount was named in honor of her captain, Commander Henry Erben, USN. Additional bathymetric data about Erben Bank, consisting of some spot soundings, were obtained by the U. S. Coast and Geodetic Survey in 1929 (USC&GS Hydrographic Survey No. H-5071). Chart 0527 also shows another shoal sounding of 240 fathoms about 200 nautical miles east of Erben Bank, at 32° 24′ N, 127° 47′ W. This unnamed seamount

was discovered in 1936 by the *USS Ramapo*. In 1947, the *USS Fieberling* made detailed bathymetric surveys of both of these seamounts using a continuously recording echo sounder. These surveys showed that both of these features have the shape of a truncated cone. This places them in the physiographic class of features which Hess (1946) has termed guyots. For convenience the previously unnamed seamount will be termed Fieberling Guyot. Also, inasmuch as Erben Bank is too deep to be properly termed a bank, it will be called Erben Guyot.[1]

To obtain more detailed information about flat-topped seamounts, a geological and oceanographic survey was undertaken by the writers from aboard the *USS EPCE(R) 857* of the U. S. Navy Electronics Laboratory in March 1948. During this survey the bathymetry was further investigated with a recording echo sounder, nine sea floor samples were obtained by dredges and snapper samplers, and bottom photographs were taken.

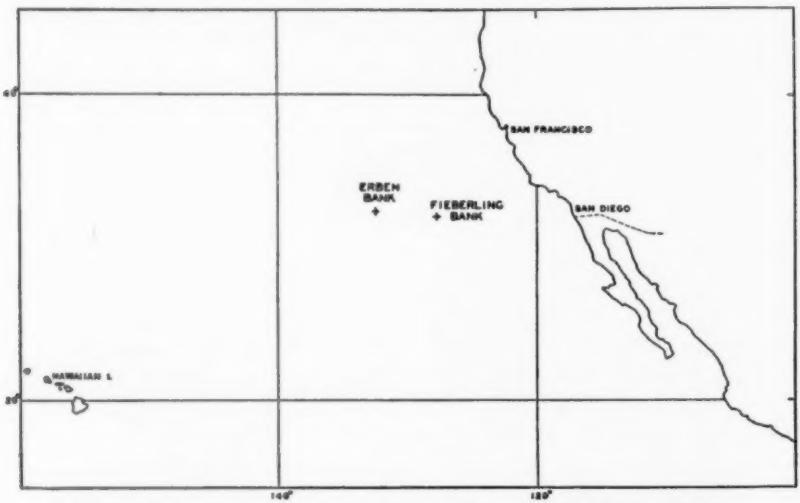

Fig. 1. Index map showing location of Erben and Fieberling Guyots.

[1] The special type of seamount termed guyots by Hess have flat tops at greater depth than the seamounts described here. However, the writers believe that these should also be termed guyots and the term bank applied only when the summit depth is less than 100 fathoms. Thus, Erben Bank will henceforth be referred to as Erben Guyot in this paper.

TOPOGRAPHY

Erben and Fieberling Guyots both rise from the abyssal ocean floor, which in this region lies at an average depth of about 2300 fathoms. Soundings obtained during the passage out from San Diego showed that level bottom extends seaward for a short distance from the continental slope off southern California, but the sea floor in the vicinity of the guyots is very irregular. The general configuration of the seamounts to a depth of 1000 fathoms is shown in figures 2, 3, and plate 1. The flanks of Fieberling Guyot have an average slope of 18 degrees; those of Erben Guyot vary between 11 degrees and 17 degrees.

Erben Guyot is characterized by a four-square mile flat surface at a depth of about 400 fathoms, from which a small peak rises to a depth of 225 fathoms. At Fieberling Guyot a five-square mile platform lies at about 280 fathoms, from which two peaks rise to 230 and 240 fathoms, respectively. The

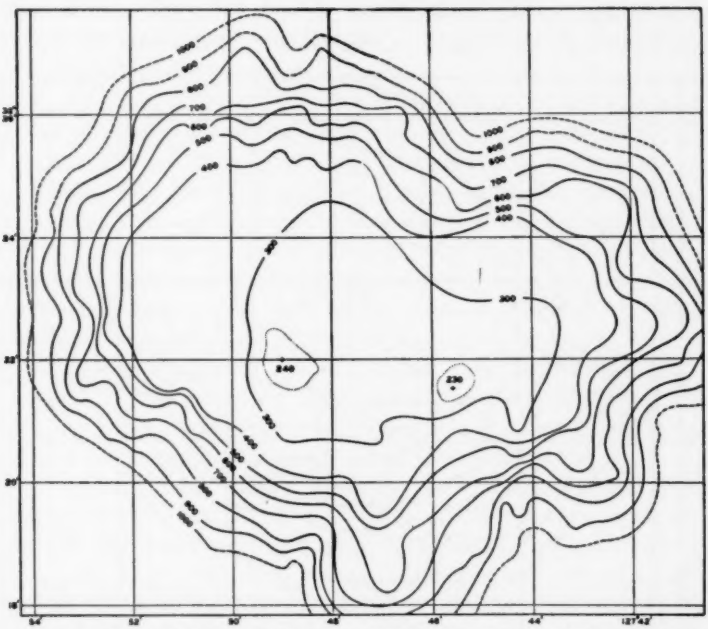

Fig. 2. Detailed topographic map of Fieberling Guyot. Contour interval 100 fathoms, except that dotted contour is 250 fathom curve. Distance between horizontal grid lines is 2 nautical miles.

sounding data are not sufficiently detailed to determine if any deep terraces or submarine canyons are cut into the flanks of these seamounts.

SEDIMENTS

General.—Information on the bottom sediments was obtained by use of a box dredge, a device mounting three snappers, and an underwater camera which trips upon contact with the bottom. The sediments from Erben and Fieberling Guyots are listed in table 1 and briefly described in table 2. Two of the four bottom photographs taken are reproduced in plate 2. Both the sampling operations and the bottom photographs show the summits to be bare, rocky, non-depositional surfaces with only occasional patches of foraminiferal sand. Great difficulty was encountered in obtaining bottom samples because of the paucity of loose detritus.

Rocks.—More than a thousand rock fragments were obtained by snappers and dredge hauls. All of the rocks are basalts or closely related types. Thin sections were prepared of one

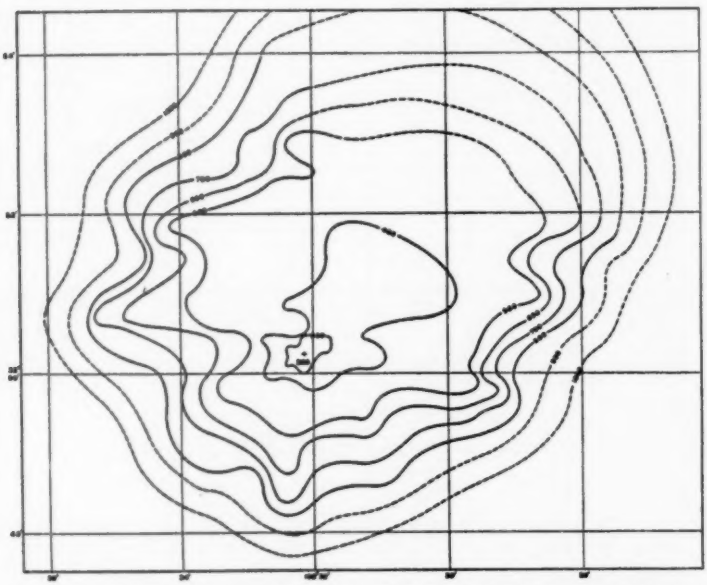

Fig. 3. Detailed topographic map of Erben Guyot. Contour interval 100 fathoms. Distance between horizontal grid lines is 2 nautical miles.

TABLE 1

Bottom Samples from Erben and Fieberling Guyots

NEL Sample No.	*Locality*	*Latitude (N.)*	*Longitude (W.)*	*Depth (Fms.)*	*Sampling Device*
662	Fieberling Guyot	32° 24′	127° 47′	273-280	Dredge
663	Fieberling Guyot	32° 24′	127° 48′	272-277	Dredge
664	Fieberling Guyot	32° 24′	127° 46′	270-280	Dredge
665	Erben Guyot	32° 51′	132° 32′	380	Snapper
666	Erben Guyot	32° 51′	132° 32′	377	Snapper
667	Erben Guyot	32° 51′	132° 32′	375	Dredge
668	Erben Guyot	32° 51′	132° 32′	375	Snapper
669	Erben Guyot	32° 51′	132° 32′	400	Snapper
670	Erben Guyot	32° 51′	132° 32′	425	Snapper

specimen from each of four dredge hauls, numbers 662, 663 and 664 from Fieberling Guyot and number 667 from Erben Guyot.

The one specimen thin-sectioned from sample 662 is a typical olivine basalt, with phenocrysts of plagioclase up to nearly one cm. in length, and rarer, smaller ones of altered olivine. These are scattered in a sub-ophitic or intersertal groundmass of plagioclase laths, granular augite and magnetite, and a little interstitial glass devitrified to a mixture of chlorite and other minerals. All of the olivine is altered to iddingsite (?) or iron oxide, with a core of serpentine (?) in some cases.

Sample 663 is a single slab of deeply weathered fine-grained basalt. In thin-section, small phenocrysts of augite and olivine occur in a groundmass of plagioclase laths, minute crystals of augite and magnetite, and devitrified glass. The devitrified glass constitutes about 60% of the rock. A spherulitic zeolite, probably phillipsite, fills fractures and small vesicles.

A pebble selected at random from sample 664 was thin-sectioned. It is extremely finegrained and dense, consisting of a microcrystalline aggregate of feldspar, augite, and magnetite, with a few larger embayed grains of iron-rich biotite.

One of the larger fragments from the breccia obtained from Erben Guyot (sample 667) was thin-sectioned. It is a vesicular olivine basalt porphyry, with lath-shaped phenocrysts of plagioclase up to about 8 mm. in length, phenocrysts of augite up to about 3 mm., and occasional smaller phenocrysts of altered olivine. The ophitic groundmass consists of plagioclase laths with interstitial magnetite, augite granules, and a little devitrified glass.

A group of angular to subrounded pebbles and cobbles is shown in plate 3, figure 1. These constitute a part of sample 662 from Fieberling Guyot. One hundred pebbles were quartered out of this sample; half of these were in the 16-32 mm. size class and half were in the 32-64 mm. class. All are basalt; about half are vesicular. Roundness of these pebbles was measured by a visual comparison method devised by Krumbein (1941) and sphericity was measured by a method devised by Pye and Pye (1943). Results of these measurements are represented graphically in figures 4 and 5. Roundness and sphericity of each pebble were plotted against each other in a scatter diagram (figure 6). In general there seems to be little correlation between roundness and sphericity. Roundness is about the same in both size classes, averaging 0.48 in the 16-32 mm. class and 0.30 in the 32-64 mm. class. Sphericity is nearly the same in both classes, averaging 0.75 and 0.73, respectively.

A copy of these results was sent to W. C. Krumbein to determine how they compared with other data on sphericity and roundness of pebbles from various environments. In his reply, Krumbein states that the roundness and sphericity dis-

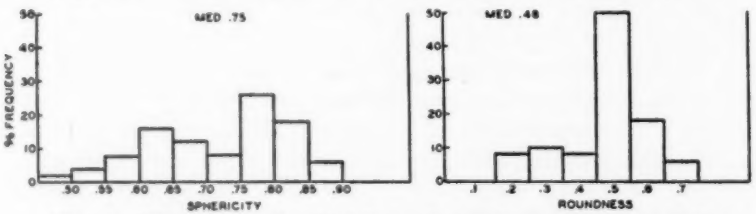

Fig. 4. Histograms of sphericity and roundness showing variation of 50 pebbles in size grade 16-32 mm. selected at random from Sample 662 (Fieberling Guyot).

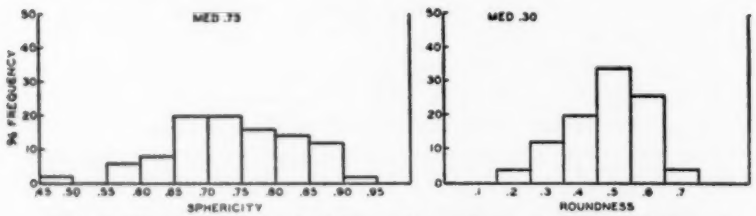

Fig. 5. Histograms of sphericity and roundness showing variation of 50 pebbles in size grade 32-64 mm. selected at random from Sample 662 (Fieberling Guyot).

TABLE 2 Description of Guyot Samples

NEL Sample Number	*Rocks*	*Authigenic Minerals*	*Organisms*
662 Fieberling	Angular to subrounded pebbles and sand composed of basalt ranging in diameter from 10 mm. to 175 mm. Includes a conglomerate of cemented basalt pebbles and one piece of foraminiferal marl.	MnO_2, possibly wad, as cement and as a veneer on the upper surface of some pebbles.	Foraminifera in crevices and holes in rocks, and in bank sand. Also ostracode tests, ophiuroids, abundant sponge spicules, and a few echinoid spines. Encrusting forms include Foraminifera, Bryozoa, serpulid worm tubes, alcyonarians, and a few solitary corals.
663 Fieberling	Large slab of weathered basaltic ledge rock.	MnO_2 as veneer on top surface.	Encrusting serpulids, solitary corals, and brittle stars, especially on the upper surface.
664 Fieberling	Angular to subrounded basalt granules, pebbles, and cobbles from 2 mm. to 175 mm. in diameter cemented together to form a breccia boulder.	MnO_2 and collophane coating sand grains and rocks, and as cement.	Foraminifera, mostly *Rupertia stabilis;* sponge spicules; fish teeth and shark teeth; a few echinoid spines; fragments of pelecypod shells; and a few euphausiids; all in a foram sand. Worm tubes, brittle stars, and Bryozoa on rock surfaces.
665 Erben		MnO_2 in slabs about 2—$1^2/_2$ to 5 cm. thick.	A few Foraminifera and sponge spicules in the MnO_2 slabs.
666 Erben		Several pieces of encrusting MnO_2	Similar to Sample 665. A few Foraminifera and sponge spicules in the bottom layer of MnO_2; also a broken gastropod shell and a sea pen.
667 Erben	A large MnO_2 coated nodule. Rock within the nodule is a $CaCO_3$ and collophane coated breccia made up of grains and pebbles of basalt 2 mm. to 125 mm. in diameter.	MnO_2 coating 5 cm. thick on the top of the nodule, 1 cm. thick on the bottom. Some collophane as cement. A few phillipsite crystals in cavities.	Foraminifera along the oldest layer of MnO_2, together with sponge spicules. Poorly preserved foraminifera and molluscan fragments in pockets within the nodule; also a few teeth of fish and sharks. Exterior of the nodule is encrusted with brittle stars, worm tubes, sponges, and Bryozoa.
668 Erben		Small fragment of MnO_2.	A few pelagic Foraminifera.
669 Erben	Basalt grains between 1/16 and 4 mm. in diameter.		Broken and complete foraminiferal tests and sponge spicules comprising over 90% of the sample.
670 Erben		Grains of MnO_2.	A few broken tests of pelagic Foraminifera, and sponge material consisting of spicules and spongin.

tributions and average values compare well with observed data for both beach and stream pebbles. The high concentration of roundness in the central class suggests beach conditions, but the sphericity distribution of the 16-32 mm. size class suggests some stream deposits Krumbein has seen. He states further that the pebbles may be part of a beach deposit, but the evidence in support of this origin is not conclusive. Krumbein also suggests the possibility that the relatively high degree of roundness of the basalt pebbles may be inherited from lapilli or volcanic bombs or from unaltered cores left by spheroidal weathering. There is no evidence from the pebbles themselves to support either of these last two possibilities. Thus it is believed that the rounding displayed by these pebbles and

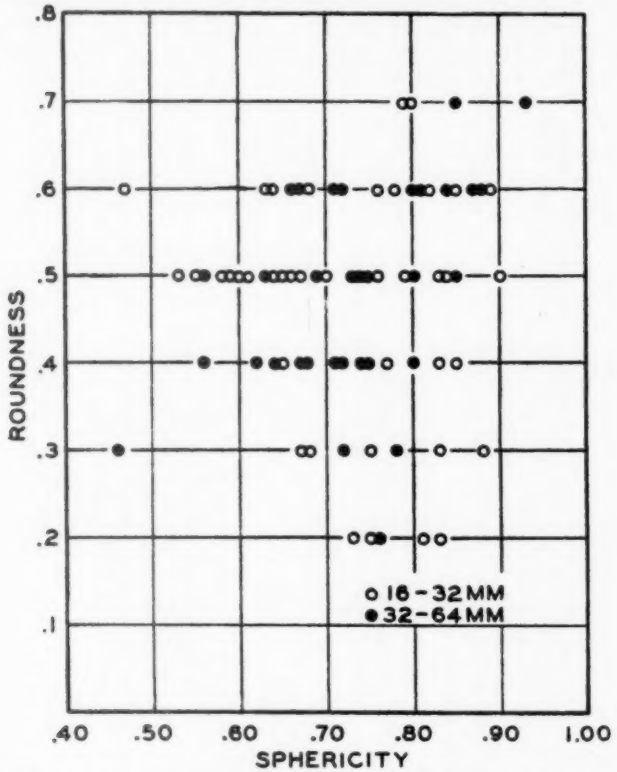

Fig. 6. Relation of roundness and sphericity for 50 pebbles in size grade 16-32 mm., shown in white circles, and 50 pebbles in size grade 32-64 mm., shown in black dots; all from Sample 662 from Fieberling Guyot.

PLATE 1

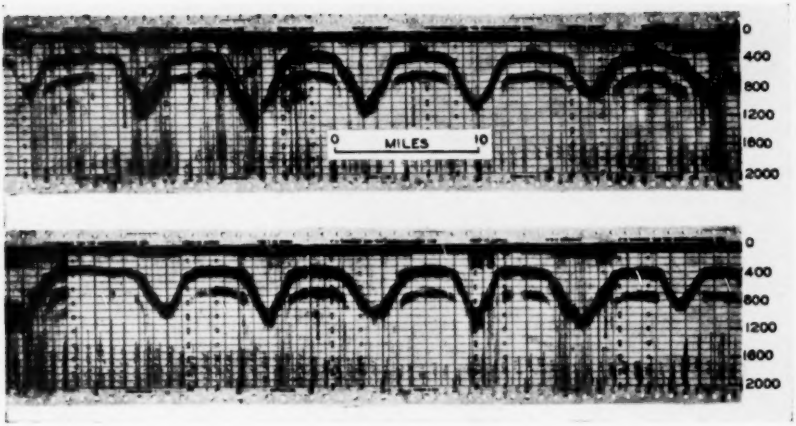

Fig. 1. Portion of fathogram showing successive crossings of Fieberling Guyot. Vertical scale exaggerated 4.8 times.

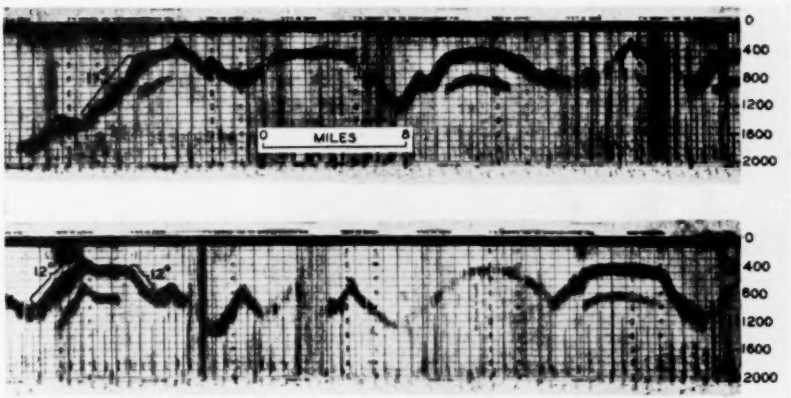

Fig. 2. Portion of fathogram showing successive crossings of Erben Guyot. Vertical scale exaggerated 3.7 times.

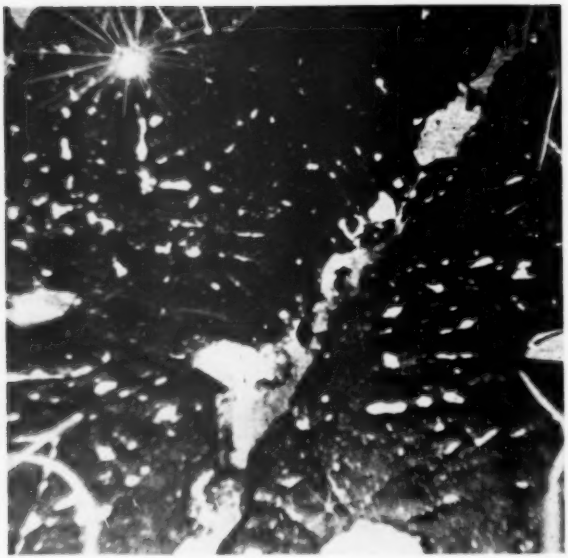

Fig. 1. Bottom photograph taken in 275 fathoms showing the basaltic surface of Fieberling Guyot. Note the echinoid in the upper left and the joint in the center of the picture which has been partially filled with globigerina ooze. The deposition of the globigerina ooze only in pockets demonstrates the existence of bottom currents competent to move the sediment. Area shown is approximately 12 square feet.

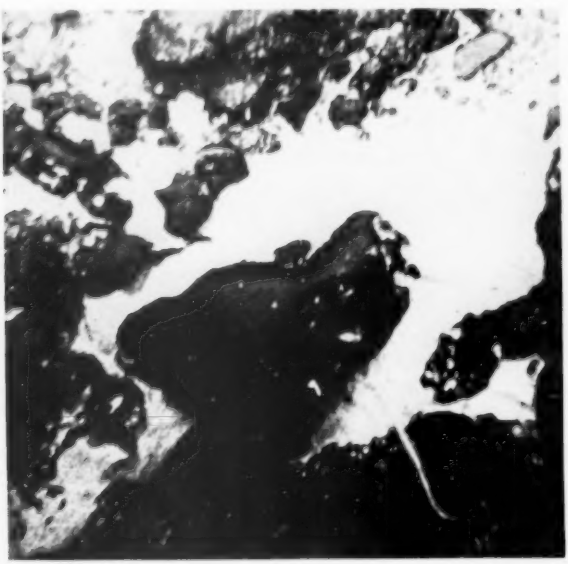

Fig. 2. Bottom photograph taken in 275 fathoms at Fieberling Guyot. Note the rocky surface covered only by large cobbles, boulders and organic detritus composed mostly of calcareous and siliceous material. The long white filament in the lower right is a "sea pen." Area is about 12 square feet.

Fig. 1. Photograph of portion of dredge sample 662 taken at Fieberling Guyot. Note subrounded nature of cobbles and pebbles. The slender object in the left background is an alcyonarian ("sea pen").

Fig. 2. Photograph of cross section of nodule dredged at Erben Guyot. The dark uppermost and lowermost layer is manganese oxide, which encrusts a breccia composed of pebbles. The fossil foraminiferal assemblage described in the report was taken from the interstitial calcareous material.

cobbles was not accomplished in their present environment. It is more reasonable to propose that they were rounded when they constituted part of a cobble beach formed during a relatively lower stand of sea level when waves truncated the seamounts.

Authigenic minerals.—The authigenic minerals identified are collophane, phillipsite and manganese oxide minerals. A small amount of collophane is present as a thin, brown polish on some mineral and rock grains and, in one place, as a cementing substance. It has also partially replaced some sharks' teeth. Small prisms of a zeolite mineral identified as phillipsite were found in cavities and vesicles in Sample 667 from Erben Guyot. Hydrated manganese dioxide was found in great abundance, especially at Erben Guyot, where it is the dominant constituent of all samples. At both guyots, manganese dioxide is present as a surface coating on most rocks, but at Erben Guyot it occurs as a thick encrustation up to two inches thick. Plate 3, figure 2 shows a large nodular mass from Erben Guyot consisting of an encrustation of manganese dioxide covering a cemented deposit of basaltic fragments and foraminifera. This manganese dioxide resembles wad, and is of the same type that is commonly found in deep sea deposits.

Organisms.—The patches of sand that occur on top of the banks are largely composed of organic remains. The bulk of the sediment is made up of foraminiferal tests. In some samples pelagic types are most abundant, but in others the benthonic form *Rupertia stabilis*, which lives attached to rocks, occurs as the flood constituent in the sediment. Other organic remains include sharks' teeth, echinoid spines, ostracode tests, and a profusion of sponge spicules. Forms which were found encrusting or attached to the rock include bryozoans, brittle stars, serpulids, alcyonarians, and *Rupertia stabilis*. However, the benthos is not abundant as on the neritic banks of similar depth near the southern California coast. This is presumably related to the relative poverty of nutrients in the surface water of this oceanic environment.

Table 3 is a faunal list of the foraminifera from Samples 664 and 669 identified by M. L. Natland of the Richfield Oil Corporation.

According to Natland (personal communication), the assemblage is unique and unlike any living or fossil fauna found along the Pacific Coast. It is likely that the fauna is largely

TABLE 3

List of Recent Foraminifera from Guyot Samples

Species	*Fieberling Guyot (Sample 664)*	*Erben Guyot (Sample 669)*
Angulogerina carinata Cushman	C	
Bolivina spissa Cushman		R
Cassidulina cushmani Stewart & Stewart		R
Cassidulina cf. *subglobosa* H. B. Brady		R
Cassidulina sp.	R	
Ehrenbergina bradyi Cushman	F	C
Epistomina cf. *elegans* (d'Orbigny)	C	
Eponides cf. *subtenera* (Galloway & Wissler)		R
Eponides sp.	C	R
Globigerina bulloides d'Orbigny		C
Globigerina inflata d'Orbigny	C	R
Globigerinoides rubra (d'Orbigny)	C	
Globorotalia menardii (d'Orbigny)	C	
Globorotalia truncatulinoides (d'Orbigny)	C	
Lagena sp.	C	
Laticarinina pauperata (Parker & Jones)	R	
Orbulina universa d'Orbigny	VA	
Rupertia stabilis Wallich	F	C
Robulus sp.	R	
Uvigerina senticosa Cushman	A	C
Vaginulina sp.	R	

Key to Abbreviations

F — Flood A — Abundant
VA — Very Abundant C — Common
R — Rare

endemic and is characteristic of an environment of a type which would not normally be represented in the marine sedimentary rocks exposed on the continents. No extinct species were identified in either of the samples. Natland states further that the benthonic foraminifera are, in general, those normally found living elsewhere at depths similar to those at which the samples were collected, but that some of the species from Fieberling Guyot are typical of greater depths.

The manganese-coated breccia (Sample 667) from Erben Guyot contained many fossil foraminifera in the limy detritus cementing the fragments of basalt (plate 3, fig. 2). Fred B. Phleger, Jr., and Miss Frances Parker, of the Scripps Institution of Oceanography, and O. L. Bandy, of the University of Southern California, have kindly examined the fossil foraminifera and expressed their opinions regarding the age of the assemblage. Phleger and Parker stated (personal com-

munication) that the fauna is tropical in aspect, but that it cannot be compared to any Recent or fossil assemblage known to them, so it may be endemic. They classified the fauna as definitely post-Cretaceous and pre-Pleistocene and most likely about mid-Tertiary. Bandy (personal communication) assigned a Miocene age to the assemblage, which is listed in table 4.

TABLE 4

List of Fossil Foraminifera in Nodule from Erben Guyot
O. L. BANDY

1. *Robulus* (Spinose and loosely coiled form, undescribed).
2. *Cassidulina cuneata* Finlay—Miocene of New Zealand.
3. *Ceratobulimina pacifica* of LeRoy (may not be the same as that of Cushman and Harris)—Miocene of the East Indies.
4. *Valvulineria inequalis* of Cushman (not d'Orbigny)—Recent.
5. *Valvulineria inequalis* var. *lobata* Cushman and Renz—Miocene of Venezuela.
6. *Hoglundina elegans* of LeRoy—Miocene of the East Indies.
7. *Uvigerina auberiana* var. *attenuata* Cushman and Renz—Miocene of Venezuela and Trinidad.
8. *Uvigerina carapitana* Hedberg—Oligocene to Miocene of Trinidad and Venezuela.
9. Globigerinidae of no age significance.

Sharks' teeth from the same nodule were sent to J. Wyatt Durham and R. H. Reinhart of the University of California. Reinhart (personal communication) identified them as from *Isurus*, which has a geologic range from Upper Cretaceous to Recent in North America. They appear to be closely related to forms from the Middle Miocene of Shark Tooth Hill, Kern County, California. However, Durham emphasizes that Tertiary sharks' teeth are not well known, so that specific criteria have not as yet been well enough established to warrant their use as index fossils.

DISCUSSION AND CONCLUSIONS

General.—Any attempt to outline the history of the guyots on the basis of the few data available is necessarily speculative. In contrast to subaerial landforms, which are subjected to vigorous erosional processes, deeply submerged submarine features are subjected to, at most, extremely slow weathering and erosion, so that one may think of them as physiographic "museum pieces." The rocky nature of the upper surface of the guyots shows that sedimentation has not masked these features. This indicates the presence of currents competent

to sweep off most of the sediment that settles from the overlying waters.

Volcanic origin.—Both the petrologic and the geomorphic evidence indicate that the seamounts originated by local submarine vent eruptions of olivine basalt which produced large volcanic cones. From the geomorphic point of view, the oval plan of the guyots and the uniformly steep flanks with a slope of about 15 degrees strongly suggest that the seamounts are extinct volcanoes. Indeed, it is difficult to conceive of any reasonable alternate explanation. The recovery of olivine basalt from the tops of the guyots furnishes additional evidence, although the presence of volcanic rock on a physiographic feature is, of course, no final proof that it is a primarily volcanic landform.[2]

Erben and Fieberling Guyots appear to be isolated volcanoes. No topographic connection between them is apparent, nor are they part of any major lineation of seamounts so far as can be determined from existing bathymetric data. Thus there is no reason to suppose that the eruptions were simultaneous or penecontemporaneous.

The olivine basalt composition is typical of the insular rocks of the Pacific Basin proper as defined by the "andesite line." This line is usually drawn along the foredeeps of the western Pacific but is often not defined in relation to the eastern Pacific, partly because of the lack of islands, to furnish petrologic data on which it can be established. The olivine basaltic composition of Erben and Fieberling Guyots is in contrast to the more acidic rocks of the islands of the continental terrace off southern California. Thus, an andesite line might be drawn between these two group of features—most logically along the base of the continental slope.

Truncation of the guyots.—The present form of Erben and Fieberling Guyots is not the initial form of a volcanic

[2] The writers' interest in examining these guyots was aroused by a sediment sample obtained from the *USS Fieberling's* buoy anchor which was planted on Fieberling Guyot. This anchor was reported to have been a new one which had never been previously used. The sediment sample had a mineral suite which could only have come from an acidic igneous and metamorphic terrane. This was difficult to reconcile with the presumed volcanic nature of the seamounts. The subsequent survey of these guyots clearly proved the spurious nature of the supposed guyot sample, re-emphasizing the probable volcanic nature of Pacific seamounts.

landform of any type. Subsequent to formation of the guyots the summits must have been eroded so that each has the form of a truncated cone. These flat summits are almost certainly planes of marine abrasion formed close to sea level.

This belief is supported by the discovery of subrounded cobbles on the top of Fieberling Guyot, which are probably explainable as beach cobbles. The lack of coral on the tops of the guyots eliminates the possibility that the flat tops are due to a drowned coral reef capping.

The writers believe with Dietz and Menard (1951) that waves erode effectively only in the surf zone, and not, as is sometimes stated, down to wave base. If this is correct, then the plane of marine abrasion must have been cut within 5 fathoms of sea level, because this is about the maximum depth at which surf forms. No known marine process except wave action near sea level is capable of vigorous enough erosion to remove such a basaltic mass with a basal area of about 20 square miles at each bank.

Inasmuch as any marine fossils found on top of the truncated basalt surfaces most likely postdate the time of truncation, the 400-fathom truncated surface of Erben Guyot, on which the fossils of probable Miocene age were found, is probably Miocene or older. No similar information is available for the 280-fathom summit plane of Fieberling Guyot, but the depth, which is 720 feet shoaler, suggests that it might be a younger abrasional surface than that of Erben Guyot. If the ideas presented below concerning subsidence of guyots are correct, it follows that, for guyots of similar mass, the depth of the truncated summit may be roughly a function of the age of the seamount.

With regard to the time of truncation, it is noteworthy that the flat tops of Erben and Fieberling Guyots are considerably shoaler than any of the large number of similar features described by Hess (1946) from the coral reef region of the west central Pacific. Hess states (pp. 777-778) that the flat upper surfaces of these guyots range from 520 to 960 fathoms. He suggests that they were formed and truncated in the Precambrian before the advent, in the Cambrian, of reef-forming organisms, and that the more recently formed volcanic islands in the coral reef seas have been preserved as atolls rather than as guyots. For reasons too lengthy to con-

sider here, the writers do not consider Hess's reasoning regarding the extremely great age of the guyots to be compelling; and, in fact, the recent recovery of mid-Cretaceous shallow water fossils from three of the west central Pacific guyots strongly suggests that these were truncated in the Cretaceous (Hamilton, 1952). From the standpoint of depth, Erben and Fieberling Guyots more closely resemble the guyots of the Gulf of Alaska (Menard and Dietz, 1951). These writers concluded that at least one of the guyots described in this paper predates the formation of the Aleutian Trench and may be pre-early Tertiary in age.

Subsidence and recent history of the guyots.—The submergence of these two guyots might have been caused in a number of ways. First, sea level might have risen absolutely because of an increase in the amount of water on the earth, or because of a decrease in the size of the ocean basins related to tectonics or to sedimentation. However, it is unlikely that a large sea level change could be accomplished in the Cenozoic by any of these mechanisms (Kuenen, 1950, pp. 532-551).

Second, large oscillations of sea level related to the locking up of water on land as glacier ice during the Pleistocene might have permitted truncation of the tops of the seamounts during some glacial maximum (sea level minimum). However, Pleistocene glaciation is considered to have been accompanied by a maximum sea level lowering of about 400 feet, which is insufficient to account for the wave cut surfaces. Also, the recovery of Miocene fossiliferous materials from Erben Guyot is evidence that the top of this guyot was not disturbed by Pleistocene oscillations of sea level.

Third, subsidence of the guyots might be caused by regional tectonic movements of the sea quite unrelated to the guyots. For example, Menard and Dietz (1951) have identified a guyot in the axis of the Aleutian Trench which they believe was submerged in part by the down-buckling of the Trench. However, much evidence has been presented to show that the central Pacific is a strong and stable mass (e.g., Hess, 1946, pp. 786-788) where epeirogenic and orogenic movements are rare. Isostatic depression of the Pacific floor caused by the loading of sediments must be a real process, but this effect would be small since the Miocene (Kuenen, 1950, pp. 545-547). To the present writers, it seems that although

regional subsidence cannot be ruled out as a possibility, it is probably not the dominant cause of drowning of these guyots.

Fourth, the guyots may have subsided because they are large superposed "rootless' masses on the earth's crust, with a strong tendency to sink. The writers believe that this is probably the dominant mechanism accounting for the submergence of the guyots. The process might be envisioned as follows: As the volcano is built up, the unconsolidated, plastic sediment underlying the volcanic pile is squeezed out. For the next few tens of thousands of years, subsidence continued at a slower but still fairly rapid rate until "isobaric" equilibrium is attained (Gunn, 1949). In isobaric equilibrium the superposed load is supported, in part hydrostatically, by the displacement of the dense and plastic asthenosphere underlying the elastic lithosphere and in part by vertical strees in the crust—thus "like a boy standing on thin ice." It may be during this initial period of subsidence that the seamount is truncated. The summits of the guyots are not so level as to preclude some subsidence contemporaneous with their cutting. Finally, even after isobaric equilibrium is attained, it seems likely that slow subsidence might continue because of slow crustal yielding related to processes like the recrystallization and slippage along crystal glide planes. These processes would result in the relief of the stresses in the earth's crust and gradual transfer of support of the superposed load to the underlying asthenosphere. The depth of the guyot platform would then be a function of the time during which these processes have acted and the mass of the superposed load.

The absence of a fossil coral cap on Erben and Fieberling Guyots is worthy of brief discussion. At the present time, the February minimum sea surface temperature in the vicinity of the banks is 15° C. Coral reefs cannot form at a temperature colder than 18° C. (Vaughan, 1916) which places the northern limit of the coral reef region about 300 miles south of these banks. In recent papers, however, Durham (1949, 1950) presents evidence that considerably warmer temperatures prevailed in this region in the past. He states (1949): "The data available indicate that in the Upper Cretaceous the February 20°C. marine isotherm along the Pacific Coast must have been some place between 50° and 55° N. Lat. and that it gradually migrated southward, possibly with minor fluctu-

ations, during the Tertiary until the Pleistocene. During the Pleistocene it obviously fluctuated both northward and southward, but the correlations available during that interval do not permit of a synthesis of the data. During the Paleocene and Eocene the 20°C. isotherm was north of 49° N. Lat.; during the middle Oligocene it was near 48° N. Lat.; in the middle Miocene it was about 35° N. Lat.; during the middle Pliocene it was around 28° N. Lat.; possibly during the upper Pliocene it was near 30° N. Lat. At present the 20°C. isotherm is near 24° N. Lat. in February." Thus, if Durham is correct, it appears that at least the temperature conditions were favorable for reef growth when these ancient islands were truncated. However, reef-producing corals and algae are highly specialized forms so that some other ecological factors may have been unfavorable for their development.

ACKNOWLEDGMENTS

The authors wish to acknowledge gratefully the assistance of the following persons and institutions who have contributed to this study of these two Pacific guyots: B. E. Holtsmark, aboard the *USS Fieberling*, made the original echo sounder surveys of the seamounts in 1946 in connection with the SOFAR program of the U. S. Navy. F. P. Shepard of the Scripps Institution of Oceanography and W. M. Buell, Jr. of the U. S. Navy Hydrographic Office assisted the authors in the 1948 survey and sampling of these guyots from the *USS EPCE(R) 857*. The Recent foraminifera were identified by M. L. Natland of Richfield Oil Corporation, and the fossil fauna was identified by O. L. Bandy of the University of Southern California and F. B. Phleger, Jr. and Miss Frances Parker of the Scripps Institution of Oceanography. J. W. Durham and R. H. Reinhart of the University of California identified the sharks' teeth from the bottom samples. R. D. Russell of the U. S. Navy Electronics Laboratory made many valuable suggestions concerning the preparation of this report and assisted the authors in other ways. W. C. Krumbein of Northwestern University expressed his opinion concerning the significance of the shape and roundness of the pebbles dredged from Fieberling Guyot. H. W. Menard, Jr. and E. C. Buffington of the U. S. Navy Electronics Laboratory critically examined the manuscript and made many valuable suggestion thereon.

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[American Journal of Science, Vol. 250, July, 1952, Pp. 498-510]

A STUDY OF THE TEXTURE AND COMPOSITION OF CHERT

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ABSTRACT. Electron microscope study of fracture surfaces of chert, using the replica technique, has shown that at least two and possibly three types of surfaces are present. Specimens which under the light microscope consist of microcrystalline quartz (minute, equant grains) show sharply defined polyhedral blocks with smooth, slightly curved faces—exactly like the shapes occupied by the air cells in soap froth. Arkansas novaculite, a very homogeneous type of chert, possesses this type of surface to a marked degree. Specimens which under the light microscope are composed of chalcedonic quartz (radiating fibers) have a more or less spongy surface, with no evidence of fibrous character when examined with the electron microscope. The sponginess is caused by the presence of abundant spherical water-filled cavities, all very nearly 0.1 micron in diameter. The bubbles impart a brownish color to the chalcedonic quartz as seen in the light microscope and decrease the density and refractive index in proportion to their abundance. Chalcedonic quartz without bubbles has the same refractive index as normal quartz. The properties of chert and chalcedony are adequately explained by the hypothesis that they consist of fine-grained quartz plus a variable quantity of water-filled cavities; there is no evidence of admixed opal. The fracture surface features are related to the mode of origin of the various types of chert.

INTRODUCTION

IT has long been known that sedimentary silica exists in at least three major modifications, those of normal quartz, chalcedony, and opal. The sequence from quartz through chalcedony on to opal is marked by decreasing grain size, increasing water content, and decreasing refractive index and density. The two end-members, quartz and opal, are distinct minerals, since opal gives the X-ray pattern of cristobalite (Levin and Ott, 1932) and is isotropic. However, the relation of chalcedony (including microcrystalline quartz) to other members of the group is less clear. Its variation in refractive index, density, and water content, combined with the fact that it yields the X-ray pattern of quartz, indicates that it is a mixture of two phases in varying proportions: quartz plus some hydrous material of lower density and refractive index. Correns and Nagelschmidt (1933) postulated that this interstitial material ("zwischenmittel") was opal. Their work was later enlarged upon by Donnay (1936b).

The purpose of this paper is to show that in the cherts that have been examined, the "interstitial material" is present, not as opal, but as very minute cavities containing water, and that all properties of chert or chalcedony may be explained by the combination of quartz with water-filled cavities.

THE HYPOTHESIS OF CORRENS AND NAGELSCHMIDT: CHALCEDONY AS A MIXTURE OF QUARTZ WITH OPAL

Correns and Nagelschmidt (1933) and Donnay (1936b) developed the theory that chalcedony is a mixture of fibers of quartz with interstitial opal. They measured the density of chalcedony, and from this figure obtained the proportion of opal presumably present in the mixture. By using the Wiener and Christiansen formulas, they computed the refractive index that would result from such a mixture, and found that the computed value agreed closely with actual measurements of the refractive index. They also attempted to determine the amount of opal by measuring the quantity dissolved by alkalies. However, no direct evidence was obtained for the existence of admixed opal in chalcedony. Donnay states (1936b, p. 301),

"Il n'a pas été prouvé directement que le constituant jouant le rôle de milieu interstitiel soit de l'opale. C'est évidemment l'hypothèse la plus plausible."

The present investigation has revealed no evidence in support of the opal hypothesis. X-ray diffraction patterns show no trace of the cristobalite pattern which should be present if opal were contained in chalcedony. Electron microscope study reveals only two phases: solid masses interpreted as quartz, and cavities. Inasmuch as quartz is harder than opal, fibers of quartz amid softer opal (as postulated by Correns and Nagelschmidt) should be readily visible on fracture surfaces when examined with the electron microscope. Such is not the case even in chalcedony specimens which are strikingly "fibrous" under the light microscope.

Although no evidence of opal was found in the specimens of chert and chalcedony studied, some intergrowths of quartz and opal may exist. However, in all the specimens we have examined, cavities containing water and not opal have been found to be the diluent of the quartz.

INVESTIGATION OF TEXTURE AND COMPOSITION

Outline of the work

Under the light microscope, chert specimens usually consist of chert and chalcedony studied, some intergrowths of quartz and optically fibrous chalcedonic quartz. Both varieties were found to contain minute water-filled cavities which decrease the refractive index and density. Under the electron microscope these two micro-forms of quartz were studied in greater detail.

Chalcedonic quartz versus microcrystalline quartz

The micro-forms of quartz, as they occur in chert, may be divided petrographically into two classes: microcrystalline quartz (following the usage of Keller, 1941), and chalcedonic quartz (plate 1, fig. 1). Microcrystalline quartz forms the bulk of most chert nodules, and is composed of subsequent interlocking grains in random orientation.[1] The individual grains in most specimens average three to five microns in diameter, and the aggregate has "pin-point" birefringence; but in other specimens, the grains are so small as to make the aggregate appear nearly isotropic. Each grain in a thin section appears to possess undulose extinction, which is due in part to the effect of many superimposed grains, but in part may also be a property of the individual microcrystal.

Chalcedonic quartz under the light microscope appears to be composed of radiating or sheaf-like bundles of fibers, each fiber not more than a few microns in diameter and ranging up to 200 microns or more in length. The fibers are not physically separable, for no fibrous structure is evident on fracture surfaces studied with the electron microscope. The break between microcrystalline and chalcedonic quartz seems to be rather sharp, although transitions do exist.

In addition to the micro-forms of quartz, chert nodules may also contain ordinary quartz of larger crystal size, showing straight extinction and normal refractive index. This "drusy" quartz usually forms the final deposit in the center of cavity fillings, while chalcedonic quartz lines the walls. This is probably due to a decreasing rate of precipitation

[1] X-ray diffraction patterns of thin sections of chert contain reflections which have the same relative intensities as reflections from powdered specimens of quartz.

because of the diminishing rate of supply of solution as consolidation proceeds. In some formations (Taliaferro, 1934) cherts are associated with large, entirely isotropic, masses of opal with low index of refraction, but the two occupy discrete areas and are not so intimately mixed that the opal affects the physical properties of the chalcedonic or microcrystalline quartz.

Presence of water-filled cavities in chert

In transmitted light, chalcedonic quartz (and, to a lesser degree, microcrystalline quartz) often appears to contain brownish zones. In reflected light, these zones become milky white. The movement of the Becke line indicates that they have a lower refractive index than the surrounding clear chalcedony. Under 1000x magnification, the brownish areas are found to be made up of a swarm of very minute, pale brownish dots. The largest of these are one or two microns in diameter, are isotropic, and have a moderate relief with refractive index below that of the enclosing chalcedony. These features are similar to the water-filled cavities in the quartz of igneous rocks. On the basis of this similarity, the brownish dots in chalcedony are also interpreted as water-filled cavities. It is believed that the cavities are filled with water and not gas, because (1) gas-filled cavities have an extreme negative relief, much greater than the relief of the observed cavities; (2) chemical analyses of chalcedony show a content of water, which, as shown later, is not present as opal, and therefore must be present as free water. The brownish color is probably due to some complex dispersion effect, caused by the difference in index.

The refractive index is a direct function of the abundance of water-filled cavities, as evidenced by the depth of brownish coloration. Bubble-free chalcedony has the same index of refraction (ordinary ray) as normal quartz. The fact that brownish areas in chalcedony have a lower refractive index was first noticed by Sargent (1929, p. 407). He ascribed it to a greater degree of hydration, but did not specify how this hydration was accomplished.

Collodion replicas were made of the surfaces of chalcedonic quartz specimens which contained most bubbles as seen under the light microscope. Electron microscope study of the replicas

revealed that the surfaces were very heavily crowded with holes, most of them spherical and about 0.1 micron in diameter. This fact indicates that the brownish dots seen in the light microscope are cavities and do not represent spherical particles of a solid such as opal.

Electron microscope study

Freshly fractured, unpolished surfaces of chert specimens were studied with the electron microscope, using the replica technique. Because of the low penetrating power of the electron beam, it is impossible to study chert specimens directly, and a very thin replica or mold of the actual surface must be made with a plastic film. One drop of a solution of amyl acetate with two per cent collodion is placed on the surface of the vertically held specimen, and allowed to spread very thinly over it. After the film has dried, the specimen is immersed in hydrofluoric acid to dissolve the chert and free the collodion film. The inner side of the plastic is then a negative replica of the surface of the chert. The replica, mounted on a 200-mesh screen, is "shadowed" with vaporized chromium to accentuate the relief, and examined with the electron microscope at magnifications of 1500 to 10,000 times.

Two distinct end-points of surface morphology were observed, together with a third, perhaps transitional type. The first we have called the "novaculite" type, because Arkansas novaculite (a very homogeneous white chert) gives the best example of this type of surface (Bates, 1949). It is characterized by sharply defined, equant polyhedral blocks with slightly curved surfaces, all blocks being about the same size (plate 1, fig. 2; plate 3). The blocks are remarkably similar in appearance to the air cells produced in a soap froth. Individual blocks which break in half usually show a featureless interior, but occasionally a somewhat terrace-like or platy structure is observed, and more rarely a conchoidal fracture appears. The novaculite-type surface occurs with varying degrees of distinctness, and shows a complete transition to the "intermediate" type. A few blocks contain small swarms of beautifully defined spherical cavities, which are almost uniformly 0.1 micron in diameter (plate 3, fig. 2).

The second, "spongy" type of surface, is found exclusively in specimens that are classed petrographically as chalcedonic

quartz. The appearance of the replica is somewhat like a piece of swiss cheese or a sponge (plate 2, fig. 1; plate 4); that is, the surface of the chert contains no discrete grains, but is permeated with tremendous numbers of small hemispherical holes, many of which coalesce to form vague tubules (plate 2, fig. 1) which tend to be parallel to each other and perpendicular to the orientation of the fibers as seen in the light microscope. Cavity-rich zones alternate with zones poor in cavities, just as seen in the light microscope. There is no evidence of fibrous character under the electron microscope.

The third, "intermediate" type of surface apparently represents a transitional stage between the novaculite and spongy types. It consists of highly irregular, somewhat indistinct areas of low relief without many cavities (plate 2, fig. 2). It sometimes contains patches showing the novaculite type surface. This intermediate type seems to be characteristic of oolitic cherts, and also of some cherts composed of massive microcrystalline quartz.

The correlation of surface morphology shown by the electron microscope with internal morphology as revealed by the light microscope is depicted in figure 1, in which the width

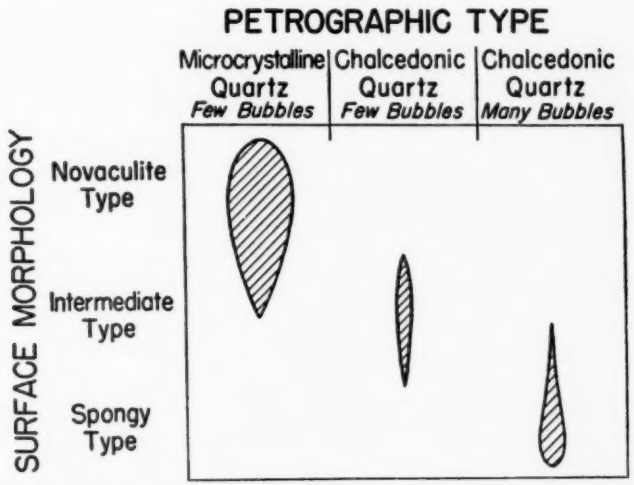

Fig. 1. Diagram showing the correlation between surface morphology and petrographic type. Width of the lenses shows the estimated relative volumetric importance of the three varieties of quartz.

of the lenses shows the relative volumetric importance of the types.

Effect of water-filled cavities on physical properties

The presence of water-filled cavities should result in a decrease of the density and refractive index of the chalcedony. To check this, the physical properties of several pieces of novaculite, which contains but few bubbles, were compared with those of several pieces of bubbly chalcedony. The novaculite is uniform petrographically, and consists entirely of microcrystalline quartz. The chalcedony, on the other hand, is composed of a chalcedonic quartz, and contains bubble-rich and bubble-free zones.

Density measurements. Replicate measurements were made on one specimen of novaculite and one of chalcedony. A five to ten gram fragment was dried in a desiccator and weighed. Then it was placed in a wire sling of known weight, submerged in distilled water at known temperature and weighed again. From each specimen, three fragments were cut, and the experiments were replicated four times; hence, twelve measurements were obtained for each specimen. The average experimental error was $\pm$ 0.0019.[2] The following results were obtained ($\pm$ range refers to one standard deviation, using $n-1 = 3$ degrees of freedom):

A. Novaculite, specimen homogeneous with few cavities:

	densities	
Piece #1	2.6422$\pm$0.0018	
Piece #2	2.6437$\pm$0.0028	
Piece #3	2.6412$\pm$0.0021	
Arithmetic mean	2.6424$\pm$0.0021	(95% confidence limits)

B. Chalcedony, microscopically fibrous with many cavities:

	densities	
Piece #1	2.6067$\pm$0.0010	
Piece #2	2.6145$\pm$0.0025	
Piece #3	2.6098$\pm$0.0014	
Arithmetic mean	2.6103$\pm$0.0037	(95% confidence limits)

It is evident that the large number of cavities lowers the density significantly.

[2] In terms of standard deviation.

PLATE 1

Fig. 1. Light microscope, crossed nicols, x 216. Thin section showing the three petrographic types of quartz: microcrystalline quartz, forming minute, equant grains; chalcedonic quartz, forming fibrous bundles; and normal quartz, forming large equant grains. The latter two varieties fill a geode in the specimen. Chert from Lower Ordovician Bellefonte dolomite, State College, Pa.

Fig. 2. Electron micrograph, x 27,700. Novaculite-type surface, showing well-defined blocks with somewhat curved surfaces. Note presence of a few well-defined bubbles. Chert from the Permian Phosphoria formation, southwest Montana.

PLATE 2

Fig. 1. Electron micrograph, x 26,650. Spongy surface, showing coalescence of bubbles to form parallel vaguely expressed tubules. Thin line is a crack in the glass negative. Chalcedony, locality unknown.

Fig. 2. Electron micrograph, x 11,750. Intermediate-type surface, showing sub-planar areas of low relief. Chert from Permian Phosphoria formation, southwest Montana.

PLATE 3

Fig. 1. Electron micrograph, x 3,290. Typical area of novaculite-type surface. Chert from the Permian Phosphoria formation, southwest Montana.

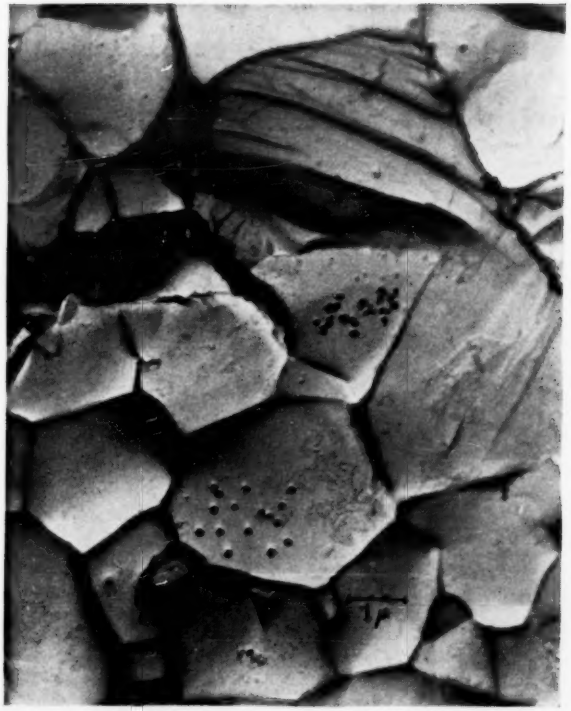

Fig. 2. Electron micrograph, x 9,400. Novaculite-type surface. One block contains a swarm of nicely-defined spherical bubbles. Chert from the Permian Phosphoria formation, southwest Montana.

PLATE 4

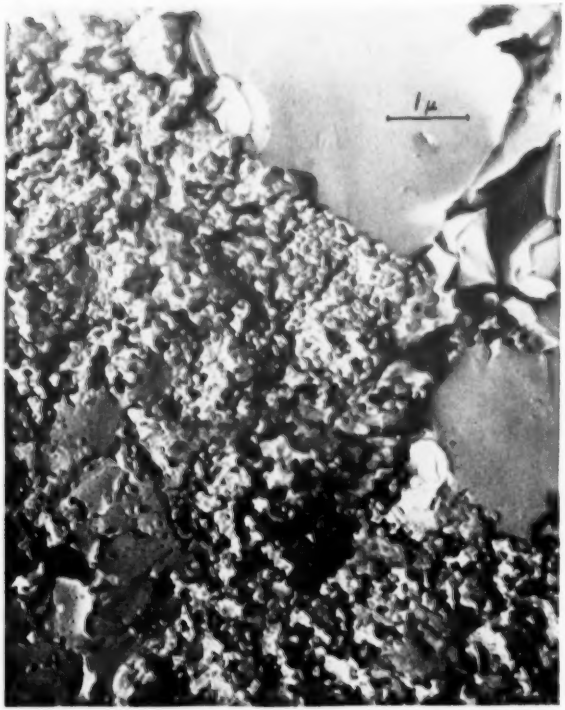

Fig. 1. Electron micrograph, x 12,690. Spongy surface, caused by the abundance of bubbles. Passes abruptly into area of rather poorly developed novaculite-type surface. Brecciated white chert from the lead-zinc deposits at Joplin, Missouri.

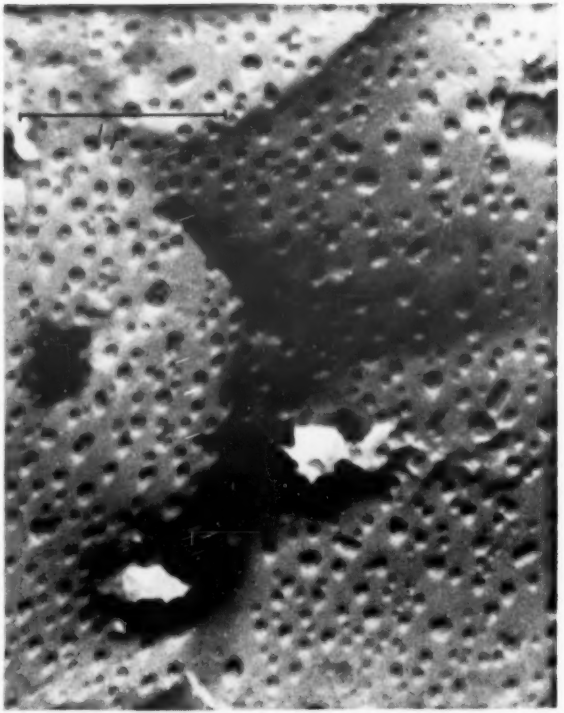

Fig. 2. Electron micrograph, x 31,490. Spongy surface, as shown in a piece of bubbly chalcedonic quartz. Note abundant spherical bubbles, and lack of fibrous structure. Milky chalcedony, locality unknown.

Index of refraction. The index of refraction of the ordinary ray was measured for both chalcedony and novaculite. The extraordinary ray was not measured because of its variation due to orientation. In all index measurements, crushed fragments of a clear quartz crystal were mixed with the fragments of novaculite and chalcedony to serve as a standard. Determinations were made by using index liquids and monochromatic sodium light. The refractive index of novaculite was found to be 1.544, the same as that of quartz. The refractive index of chalcedony varied from 1.544 where the chalcedony was colorless (hence free of cavities) to 1.540 in places where the chalcedony was brownish and filled with cavities. Due to the close spacing of bubbly and non-bubbly zones, no mathematical correlation between refractive index and density was attempted. The concept of form birefringence (Donnay, 1936a) is not believed to be applicable because it requires the existence of fibers or plates of one substance embedded in another substance of differing refractive index; in the chalcedony studied, quartz plus cavities are the only two phases, and there is no evidence of physically discrete fibers or plates.

Other physical properties. In order to ascertain the elements that might be present in traces in the water contained in the cavities, one sample of chalcedony and one of novaculite were sent to Mr. Howard W. Jaffe, of the U. S. Bureau of Mines for spectrographic analysis. He obtained the following results:

Estimated percentage	*Chalcedony*	*Novaculite*
0.5 - 5.		Fe
0.1 - 1.	Al	
0.01 - 0.1	Na, Fe, Mg	
0.01	Ca	Na, Al, Ba, Sr, Mg

No definite conclusions can be drawn from two samples; however, the presence of appreciably more sodium and magnesium in the chalcedony may indicate the presence of saline water in the cavities.

Differential thermal analysis showed the normal quartz inversion at 573°C, although it was somewhat subdued. X-ray patterns revealed nothing but the normal quartz structure.

HYPOTHESIS ON THE FORMATION OF CHERT

Any hypothesis concerning the origin of chert should take

into account the following properties of the two types of quartz of which it is composed:

Microcrystalline quartz: Optically, it consists of minute equant grains in random orientation, and under the electron microscope it shows distinct, polyhedral equant grains. Generally there are few cavities. This form usually occurs as a replacement of limestone.

Chalcedonic quartz: Optically, this consists of radiating bundles of fibers. Under the electron microscope, it seems to be massive and homogeneous with no evidence of fibrous nature or of distinct grains. There are alternating zones containing few to many cavities, which give the fracture surface a spongy appearance under the electron microscope. This material usually occurs as a direct precipitate or cavity-filling and much less commonly replaces limestone.

Origin and growth

Using the above facts, the writers have developed the following hypothesis to account for these characteristics as a function of the manner of growth.

The primary factor determining whether microcrystalline or chalcedonic quartz will form is believed to be the spacing of the centers of crystallization. It is suggested that microcrystalline quartz results when crystal growth begins at very numerous, closely spaced centers arranged in a three-dimensional array. The individual microcrystals, in random orientation, grow in all directions until they meet the advancing edges of adjacent microcrystals. If all crystallization centers are evenly spaced, the resulting microcrystals will form equant, polyhedral blocks of sub-uniform size such as those observed with the electron microscope. The surfaces of the blocks are slightly curved because they do not represent crystal faces, but merely the interface between two conformable masses—exactly as the interfaces between separate air cells in a soap froth have curved surfaces, defining equant, polyhedral, rather uniformly-sized blocks. The rate of formation presumably governs the closeness of the spacing, and this in turn determines the grain size of the chert.

Chalcedonic quartz, on the other hand, starts formation from only a few centers of crystallization, and because of

the limited interference gives rise to optically continuous fibrous structures. The most favorable condition for the formation of chalcedonic quartz occurs when crystallization begins at a few centers spaced along a *surface*, in which case outward growth is unhampered. More rarely, chalcedonic quartz may also result from a three-dimensional array of centers, providing these are widely spaced.

Inherently, then, it would appear that either microcrystalline or chalcedonic quartz could form by replacement, and either type could form by direct precipitation, inasmuch as the sole controlling factor governing the type of quartz produced is the spacing and distribution of crystallization centers. However, petrographic evidence shows that most microcrystalline quartz forms by replacement. Evidently, when carbonates, either as an ooze or possibly as a consolidated mud, are replaced by chert, the silica begins to form essentially simultaneously at centers spaced closely throughout the rock, resulting in the formation of the polyhedral blocks described. On the other hand, almost all directly precipitated cavity-fillings are composed of chalcedonic rather than microcrystalline quartz. This is to be expected, because crystallization starts at centers spaced along the surface of the cavity. In cases where fossils have been replaced by chalcedonic quartz, replacement starts from a few centers spaced along the shell boundary, the quartz eating its way through the shell. Here again, crystallization starting from a surface favors the production of chalcedonic rather than microcrystalline quartz. These ideas are summarized in the table at the bottom of page 508.

Chemistry of growth

A possible explanation of the two types of fracture surfaces of chert can be derived by applying principles of surface chemistry advanced by Weyl (1948). When a crystal consists of highly polarizable anions of large size, together with small, highly charged cations, then the anions will be pushed to the surface of the crystal and the cations will be recessed. Thus in a microcrystal of quartz oxygen ions predominate at the surface, while the silicon ions are depressed. It is believed that each microcrystal of quartz then has a negatively charged "skin," and effectively repels adjacent randomly oriented mi-

crocrystals. When a specimen of chert composed of microcrystalline quartz is broken, fracture probably takes place between the polyhedral blocks because of the surface repulsion forces.

In chalcedonic quartz, on the other hand, it appears likely that large continuously oriented masses are built up by the regular accretion of ions at the edge of the growing lattice. Because of the uniform orientation over large areas, no negatively charged surface of oxygen ions is formed, and the chalcedonic quartz as seen in the electron microscope shows a continuous surface with no evidence of distinct grains or fibers. The bond strength between the subparallel lattices of adjoining fibers is strong enough so that the material does not fracture between the fibers. Of course, the fibrous character observed in the light microscope shows that the quartz lattice is arranged in a radial fashion, but the change in orientation is apparently so gradual that no anion skin results.

Mode of Formation	*Probable Rate of Formation*	*Arrangement of Crystallization Centers*	*Type of Quartz Resulting*	*Volumetric Importance*
Replacement of Carbonates	rapid	3-dimensional, close	fine-grained microcrystalline	Extremely abundant
	slow	3-dimensional, distant	Coarse-grained microcrystalline, transitional to fine-grained chalcedonic	Uncommon
	slow	2-dimensional, distant	fine-grained chalcedonic, somewhat transitional to types above and below.	Uncommon
Direct Precipitation into cavities	slow	2-dimensional, distant	coarser-grained chalcedonic	Fairly abundant
	rapid	2-dimensional, close	microcrystalline	Rare
Recrystallization of gel, or of opal.			Either type, depending on arrangement of crystallization centers.	Uncommon

Water bubbles are much more abundant in chalcedonic quartz, apparently because the latter usually grows by direct precipitation into water-filled cavities, thereby trapping a large amount of the water. This process is presumably facilitated by the hydrophilic character of quartz. Zonal variation in the abundance of bubbles may be caused by changes in the hydrophilic tendency, depending on rate of growth, temperature, or chemical character of the solution. Microcrystalline quartz, on the contrary, traps less water because it commonly forms as a replacement of limestone, which may either be solid (as in the case of limestone pebbles) or unconsolidated lime ooze. The nature of the replacement process, entailing volume-for-volume substitution of the quartz lattice for the calcite lattice, may inhibit the formation of water bubbles for reasons yet unknown.

CONCLUSIONS

1. Chert specimens are composed of two petrographic end-members: microcrystalline quartz and optically fibrous chalcedonic quartz. In the specimens studied there is no evidence for the presence of any opal admixed in chalcedony or chert.

2. Minute cavities present in zones in chalcedonic quartz are recognized by their apparent brownish color in the light microscope, and are easily seen in the electron microscope. It is believed that these cavities are filled with water.

3. Water-filled cavities are the cause of the lower refractive index and density of microcrystalline quartz and chalcedony as compared with normal quartz; and the values of the physical properties change in proportion with the abundance of the cavities. Chalcedony and microcrystalline quartz have the same properties as ordinary quartz when free of bubbles.

4. Electron microscope studies reveal that fracture surfaces of microcrystalline quartz aggregates consist of well-defined, polyhedral blocks, and that surfaces of bubbly chalcedonic quartz have a very spongy appearance. An intermediate type shows poorly defined sub-planar areas.

5. It is suggested that the spacing of the initial centers of crystallization governs whether microcrystalline or chalcedonic quartz will form. Replacement generally favors close spacing, resulting in the formation of microcrystalline quartz. Direct precipitation into cavities favors wide spacing and the formation of bubbly chalcedonic quartz.

ACKNOWLEDGMENTS

The writers would like to acknowledge the kind help of Dr. Thomas F. Bates, under whose direction the electron microscope phase of the work was done, and who gave helpful criticism in the writing of the manuscript. The present research developed as a result of work by Folk on the Ordovician cherts of Central Pennsylvania and Weaver on the Phosphoria formation of Montana, and thanks are extended to Dr. Paul D. Krynine for his help in this petrographic phase of the work. Thanks are also due Mr. Howard W. Jaffe, of the U. S. Bureau of Mines, who made a spectrographic analysis, Miss Ethel Senkovits, who operated the electron microscope, and Mrs. David F. Conover, who assisted in the photography. This research was supported by the School of Mineral Industries of The Pennsylvania State College.

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[American Journal of Science, Vol. 250, July, 1952, Pp. 511-522]

THE MIDDLE DEVONIAN CHERRY VALLEY LIMESTONE OF EASTERN NEW YORK

LAWRENCE V. RICKARD

ABSTRACT. The Cherry Valley limestone member of the Middle Devonian Marcellus formation of New York is poorly known in the eastern portion of the state. In the summer of 1950 the author undertook the mapping and location of new outcrops of this limestone member.

As a result, the number of known outcrops in the east has been increased from four to over thirty. The limits of the member and its thickness were determined. The limestone was found to extend across the Berne Quadrangle where outcrops were previously unknown. The known geographic distribution of certain common Cherry Valley cephalopods was extended, and additional specimens of *Agoniatites nodiferus* (Hall) were discovered in a small, restricted lens. *Werneroceras plebeiforme* (Hall) was found to have a much wider geographic range than was previously known.

INTRODUCTION

THE primary purpose of this study was the location of new outcrops and the mapping of the Cherry Valley limestone member of the Marcellus shale in eastern New York, and, secondarily, a study of the fauna and a determination of the limits and thickness of the limestone. Figure 1 shows the extent of the Cherry Valley limestone as studied and described in this report.

The Cherry Valley limestone was originally the "Goniatite" or "Agoniatite" limestone of Vanuxem (1842) in the early geologic survey of New York State. It is noted for its unique assemblage of cephalopods, particularly species of *Agoniatites*. Clarke (1903) proposed the geographic name, Cherry Valley, for the fine exposure of this limestone at Cox's Ravine, ¾ mile northwest of Cherry Valley, Otsego County, New York. Here approximately 5 feet of limestone is considered to be typical of this member of the Marcellus formation of the Middle Devonian Hamilton group. It is unknown west of Flint Creek, at Phelps, New York. It extends eastward for 160 miles across New York State to Onesquethaw Creek, near Clarksville, Albany County. Previous work on the Cherry Valley has been done mainly by Clarke (1901), Grabau (1906), Cooper (1930, 1933), Smith (1935), and Flower (1936, 1943).

PHYSICAL CHARACTER AND EXPRESSION

The Cherry Valley is typically a black, bituminous and impure limestone marked on the outcrop by an orange-red iron stain and hackly fracture. Some layers are coarsely crystalline while others are very fine grained. There is an increase in the pyrite content to the east. On the Berne Quadrangle nodules of pyrite ⅛ to ½ inch in diameter are found quite abundantly in the lower layers. When broken, the limestone sometimes yields an odor of petroleum. The thickness varies slightly but in general increases from 0 to 3 feet in western and central New York to 14 to 25 feet in the Berne Quadrangle, where it contains much dark gray, calcareous shale. The limestone is divided into two unequal and somewhat massive parts by a layer of shaly limestone or shale having limestone nodules 2 to 4 inches in thickness. This noduliferous layer was found to be quite persistent throughout the eastern area and proved to be a great aid in the correlation of outcrops.

GENERAL STRATIGRAPHIC RELATIONS

Cooper (1930) proposed the name Union Springs member of the Marcellus formation for the black, carbonaceous, pyri-

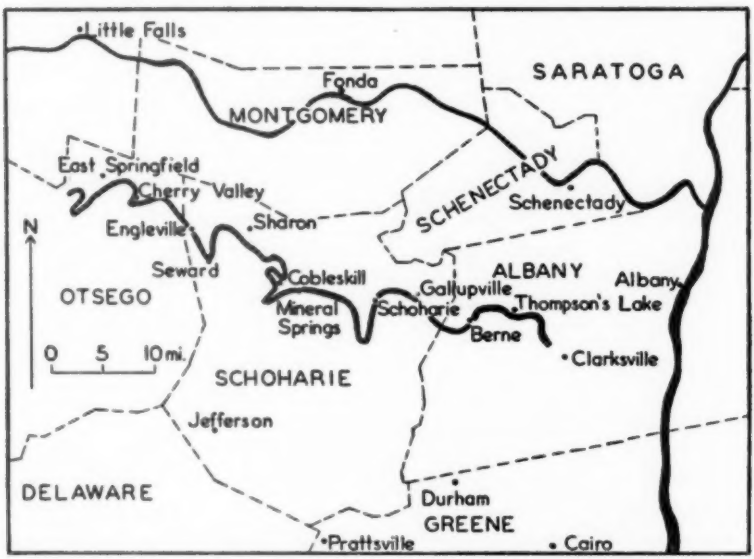


Fig. 1. Map of the eastern portion of the Cherry Valley limestone.

tiferous and very fissile shale between the Onondaga and Cherry Valley limestones. The upper portion of the Union Springs shale is characterized by numerous calcareous concretions and thin limestone layers. These limestone bands become more abundant westward but die out to the east. The member extends from Union Springs, Cayuga County, the type section, eastward to Schoharie and across the Berne Quadrangle. It contains the pelagic *Styliolina* fauna typical of the black mud phase. According to Cooper, the Union Springs is 17 feet thick at the type section. It is 35 to 40 feet thick at Cherry Valley and 70 feet at Schoharie. Tracing of the Cherry Valley limestone across the Berne Quadrangle now permits more accurate estimates of the thickness of the Union Springs in the extreme eastern portion of its outcrop, where it is approximately 80 to 90 feet thick.

The westward thinning and disappearance of the Union Springs beyond Cayuga Lake suggests a merging of the Cherry Valley with the top of the Onondaga limestone. Clarke and others have regarded the upper 50 feet of the Onondaga limestone of the west as contemporaneous with the Union Springs shale in the east (Goldring, 1935, p. 212). Further study of the western Cherry Valley is needed to determine this point.

Overlying the Cherry Valley limestone is the Chittenango shale (Cooper, 1930), a jet-black, fissile shale extending from Union Springs to Schoharie. It is nearly barren of fossils and non-calcareous except for its basal portion near the contact with the Cherry Valley. South of Chittenango Falls it is 120 feet thick, and Cooper indicates that its thickness increases to 150 feet in the Unadilla Valley and to approximately 185 feet near Schoharie (Goldring, 1943, p. 238).

Cooper and Goldring (in Goldring, 1943, p. 247) established the correlation of the Cherry Valley limestone with the Stony Hollow sandstone. The Stony Hollow is a fine-grained, calcareous sandstone easily recognized by its compactness, resistance to erosion, and strong jointing. When fresh it has a dark gray color, but it weathers to a light gray, punky sandstone by leaching of the lime. It was named by Cooper (in Goldring, 1943, p. 247) for the exposures at the entrance to Stony Hollow, 3 miles northwest of Kingston, where it is 75 to 80 feet thick. It extends from Port Jervis northward to Onesquethaw Creek where thin limestone layers indicate its

gradation laterally into the Cherry Valley. The Onesquethaw section, starting approximately 165 feet above the Onondaga, reveals 11 feet of pyritiferous sandstone overlain by 9 to 10 feet of dark, weaker shales somewhat pyritiferous in the lower portion, topped by 5 feet of limestones similar to the typical Cherry Valley and containing *Agoniatites vanuxemi* (Hall). The total thickness of the Cherry Valley (or Stony Hollow) here is approximately 25 feet.

By this correlation the Bakoven shale (Chadwick, 1933) of the Hudson Valley, underlying the Stony Hollow, is established as the equivalent of the Union Springs shale. This is a thin-bedded black shale, with sandy Cardiff-type shale in the upper portion, averaging 140 to 200 feet in thickness (Goldring, 1943, pp. 241, 244), and carrying a fauna similar to that of the Union Springs.

Previous to the correlation of the Stony Hollow with the Cherry Valley all the shales in the Berne Quadrangle from the Onondaga limestone to the *Meristella* bed at the base of the Otsego shale were termed the Berne member (Cooper, 1933), including undifferentiated Union Springs, Cherry Valley, and Chittenango members, and, according to Cooper and Goldring, are 282 feet thick at East Berne (Goldring, 1935, p. 189; 1943, p. 238). However, the correlation of the Stony Hollow with the Cherry Valley necessitated a redefinition of the Berne member. Cooper redefined the Berne as the shales between the Cherry Valley horizon and the *Meristella* bed and estimated it to be 100 to 150 feet thick (in Goldring, 1943, p. 249). His estimate is evidently based upon the thickness of the Union Springs (or Bakoven) in Onesquethaw Creek and is too low. As was noted above, the thickness of the Union Springs throughout the major portion of the Berne Quadrangle is 80 to 90 feet. Thus, allowing for the combined thicknesses of the Union Springs and Cherry Valley (the latter being 14 to 25 feet thick), the restricted Berne member would appear to be 170 to 190 feet thick on the Berne Quadrangle.

THE CHERRY VALLEY LIMESTONE IN EASTERN NEW YORK

Stratigraphy.—Figure 2 is a chart showing stratigraphic sections of the Cherry Valley limestone in eastern New York. All of these outcrops are waterfalls in small stream beds. Fifteen exposures studied were suitable for accurate measure-

ment. Three of these were previously known, one of them the type section. The datum plane of these sections is the base of the noduliferous shaly layer between the two main limestones of the Cherry Valley.

The upper limit of the Cherry Valley limestone is drawn at the contact of the uppermost massive limestone layer with the overlying black shales of the Chittenango. In the few outcrops exposing this contact, as at Seward or Mineral Springs, the basal portion of the Chittenango is calcareous but has no noticeable bands of limestone.

Determination of the exact lower limit of the Cherry Valley was first attempted by Flower (1943). He concentrated his efforts on two outcrops, the type section at Cherry Valley and an outcrop near Stockbridge, Madison County. At the type section the first massive limestone layer (counting from below) having the typical fauna and lithology of the Cherry Valley occurs at the brink of the falls (Cooper, 1933). Some distance beneath this layer occurs a thin limestone band containing *Werneroceras plebeiforme* (Hall). Immediately above the *Werneroceras* bed are dark shales containing *Agoniatites nodiferus* (Hall). Flower was able to locate the *Werneroceras* zone at Stockbridge but failed to find *A. nodiferus*. The *Werneroceras* zone contains such species as *Styliolina fissurella* Hall, *Lunulicardium marcellense* Vanuxem, *Tornoceras* sp., *Panenka ventricosa* Hall, and a bellerophontid gastropod (Flower, 1943, p. 16). On the basis of position, lithology, and fauna of this limestone layer he placed it in the Union Springs shale, and the lower boundary of the Cherry Valley at the base of the massive limestone layer at the crest of the falls.

The westernmost outcrop studied by the writer is at Pine Cobble Hill, on Continental Road, 1.7 miles southwest of East Springfield (fig. 2, section 1). This outcrop was discovered by Cooper (1933) and is 4 miles west of the type section. The Cherry Valley here contains several more shaly layers than at the type section but the two main divisions, separated by a thin noduliferous layer, can be recognized. Fourteen inches below the lowest layer having typical Cherry Valley lithology occurs an argillaceous limestone about 6 inches thick containing *W. plebeiforme*. This suggested that the *Werneroceras* zone is persistent and might be useful in determining the base of the Cherry Valley, and, indeed, it has proved to

be most useful. The *Werneroceras* zone was found at three more outcrops east of the type section (fig. 2, sections 12, 24, and 33) where specimens were found in place. At three more (sections 15, 19, and 30) its position can be estimated with a fair degree of accuracy. At most of these localities the *Werneroceras* zone is approximately one foot beneath the lower division of the Cherry Valley. Found with this cephalopod are *Proetus haldemani* Hall (quite abundant), *Loxonema* cf. *minuscula* (see Clarke, 1901, p. 122) and *Stereoelasma rectum* (Hall).

In the Berne Quadrangle the *Werneroceras* zone is an invaluable aid in determining the lower limit of the Cherry Valley. At the Thompson's Lake outcrop (fig. 2, section 33) the *Werneroceras* zone is no longer a limestone layer. Here two large calcareous concretions enclosed in black, fissile shale yielded 13 specimens of *Werneroceras plebeiforme*, together with *Camarotoechia prolifica* (Hall), *Palaeoneilo constricta* (Conrad), *Nucula bellistriata* (Conrad), *Bembexia capillaria* (Conrad), *Trepospira rotalia* (Hall), *Naticonema lineata* (Conrad), and an unidentified orthoconic cephalopod. The 9-inch limestone layer 11 feet above the *Werneroceras* horizon is interpreted as the base of the Cherry Valley limestone at this locality. This limestone is overlain by 13½ feet of dark-gray, calcareous shale with three limestone layers of which at least the uppermost contains *Agoniatites vanuxemi* (Hall). Above this occurs 4½ feet of limestone having typical Cherry Valley lithology which may be separated into two divisions by the noduliferous layer. Thus 18½ feet of shales and limestones are here considered as Cherry Valley. The section in Onesquethaw Creek, two miles southeast, is quite similar and has already been discussed. The *Werneroceras* zone was not located here but it may exist in the form of concretions as at Thompson's Lake.

Structure.—Throughout the area studied the Cherry Valley limestone has a regional dip of approximately 110 feet per mile to the southwest. Excepting a low fold in the limestone at the type section, described by Flower (1936, p. 6), no other major structural features were noted in the Cherry Valley. At five of the outcrops studied a very interesting structural feature was observed in the upper portion of the Union Springs shale. For a distance of 34 miles from Onesquethaw Creek

westward to Seward there is a zone of crumpled black shale which varies in thickness and position. Figure 2 shows the occurrence of this disturbed zone. A slight indication of this zone exists farther west at the type section of the Cherry Valley. The zone is evidently continuous and appears to be limited to the upper Union Springs. The shales are folded and broken and have a shiny, slickensided appearance. Concretions in the shales are tilted. The folds are sharply truncated above and below by normal, flat-lying black shales. In some places the crumpled zone is found immediately beneath the *Werneroceras* limestone. Slickensides trending NW-SE were found just beneath the limestone at such places. About an inch of black, powdered shale was found at Seward between the limestone and the crumpled shale. Several hypotheses could be advanced to explain the origin of this crumpled shale zone, but none appears to be very satisfactory.

Fauna.—The origin and preservation of the Cherry Valley fauna was discussed by Flower (1936) in the first of two papers on the Cherry Valley cephalopods published in the *Bulletins of American Paleontology*. In the same paper he set forth the conditions under which the Cherry Valley limestone was deposited. In the second paper (Flower, 1943) he noted the position of the fauna in the limestone. For details on these points the reader is referred to these papers.

The fauna of the Cherry Valley limestone is listed in table 1, which also shows the known distribution of all species at the present time. In addition to these Cooper (in Goldring, 1943, p. 248) reports a *Pentamerella* sp. and a *Dechenella* sp. as occurring in the Cherry Valley. Some points may be made concerning the distribution of several common Cherry Valley forms. *Striacoceras typum* (Saemann) was found to extend only as far as the extreme western border of the Berne Quadrangle. *Agoniatites vanuxemi* (Hall), reported by Flower (1943, pp. 6, 11) as not extending to Schoharie, was found to continue eastward across the Berne Quadrangle to Onesquethaw Creek. This would seem to indicate that *A. vanuxemi* was a near-shore species despite Flower's supposition to the contrary (Flower, 1936, p. 13). However, it must be remembered that these eastern occurrences may be due to empty conchs floating about after death.

A comparison of papers by Clarke, Flower, and Miller

TABLE 1

GEOGRAPHIC DISTRIBUTION OF THE CHERRY VALLEY FAUNA

CEPHALOPODA	ERIE COUNTY	CANANDAIGUA LAKE	FLINT CREEK, PHELPS	WOOD'S QUARRY, UNION SPRINGS	SKANEATELES QUADRANGLE	MANLIUS	STOCKBRIDGE	E. SPRINGFIELD	CHERRY VALLEY	ENGLEVILLE	SEWARD	SHARON	LAWYERSVILLE	WARNERVILLE	COBLESKILL	MINERAL SPRINGS	SCHOHARIE	GALLUPVILLE	BERNE	BERNE QUADRANGLE	THOMPSON'S LAKE	ONESQUETHAW CREEK
ACLEISTOCERAS ? DILATATUM																	2,3					
A. FISCHERI						2,3,9																
A. JONESI							3,4															
AGORATITES FLOWERI						1,3	1,2,3															
A. INTERMEDIUS				2,3																		
A. VANUXEMI	2,9	2	9	2,9	7	1,2,9	1,2	R	2,9 R	R	R	R	R			R	9? R	R			R	R
CASTEROCERAS ALTERNATUM						2,3,9	2,3		2,3								3,3,5,9					
CENTROCERAS MARCELLENSE				2		2,9	2										2,5			2		
DIADEMOCERAS PALMERI							11															
DIAGOCERAS APTUM				2,3	2,3	2,3,9	2,3										2,3					
LOBOBACTRITES CLAVUS							1,2		2								1,2			1,2		
LYRIOCERAS DUBIUM						2,3,9																
L. LIRATUM						2,9																
MICHELINOCERAS NOVEBORACENSE						9																
M.? SWARTHI				2,3			2,3															
M.? UNICONSTRICTUM						9																
MICRONOCERAS GIBBOSUM							2										2					
NEPHRITICERAS BUCINUM						2,9																
OVOCERAS CONSTRICTUM						2,3	2,3										2,3					
O. OVIFORME				4		2,3,9	4										2,3,5,9					
PALMEROCERAS FUSTIS						2,9											2,3,5					
POTERIOCERINA SOLIDA						2,9																
SPYROCERAS GENEVA									2													
S. NUNTIUM						2																
STRIACOCERAS RIONOCERIOIDES							2,3															
S. TYPUM		2		2	2,7	2,9	2	R	2 R	R	R			R	R	R? R	2,5	R		2		
TETRANODOCERAS TRANSVERSUM				2	2	2	2		2								2					
TORNOCERAS (PARADOCERAS) DISCOIDEUM				2		1,2,3	2										1,2,5,9			2		
T. (TORNOCERAS) UNIANGULARE	3?				1																	
VERTICOCERAS CONRADI						2,3,9											3,5,9					
V. ERECTUM						3	4										2,3					
V. SP.																	2					
MISCELLANEOUS																						
AULOPORA SP.									4									R	R			R
AMBOCOELIA CF. NANA									9													
LEIORHYNCHUS LIMITARE					7	6,9		R	4	R			R	R		R	R	R				
L. MYSIA																	5					
SCHUCHERTELLA CHEMUNGENSIS VAR. ARCTOSTRIATA														R								
CHAENOCARDIOLA CURTA						9																
LUNULICARDIUM CURTUM						6																
L. RUDE																	5					
PANENKA VENTRICOSA						6,9				R							5					
EUOMPHALUS PLANODISCUS						6,9,10																
LOXONEMA DELPHICOLA						6,9				R												
MACROCHILINA ONONDAGAENSIS						6,9			4													
PLEUROTOMARIA RUGULATA						6		R		R				R			10 R					
COLEOLUS ACICULATUM						10		R	4	R						R						
C. SP.									4													
STYLIOLINA FISSURELLA					7																	
MESOTHYRA ? SP.						9																
PROETUS HALDEMANI						6			4,9													
ARTHRODIRAN PLATES					7	6																

KEY

1. MILLER 1938
2. FLOWER 1936
3. KINDLE & MILLER 1939
4. FLOWER 1943
5. GRABAU 1906
6. WILSON 1903
7. SMITH 1935
9. CLARKE 1901
10. HALL 1860
11. FLOWER 1949

R. REPORTED BY THE AUTHOR

indicates some confusion as to the exact positions at the type locality of the *Werneroceras* zone and the *Agoniatites nodiferus* horizon. Flower (1936, pp. 6, 11, 76, and personal communication) states that *A. nodiferus* occurs in the writer's noduliferous shaly layer, which divides the sequence of thick, massive layers of limestone into two divisions, i.e., within the Cherry Valley limestone itself. *Werneroceras* is said to occur "below the lower layer." On the other hand, Miller (1938, pp. 48, 60-61), Clarke (1901, pp. 121-122) and Flower (1943, pp. 17-19) indicate that *A. nodiferus* occurs immediately above the *Werneroceras* zone below the base of the Cherry Valley. Further confusion arises from the fact that the type section is atypical, there being several more limestone layers in the upper Union Springs than at other localities.

As mentioned in the preceding portion of this paper, the *Werneroceras* zone occurs 14 inches below the base of the Cherry Valley at Pine Cobble Hill, 4 miles west of the type section. However, *A. nodiferus* was not found at this locality, where the lithology of the *A. nodiferus* horizon, accepting the second sequence described above, has changed to a thin-bedded, barren shale. At the type section the author found *A. nodiferus* immediately above the *Werneroceras* limestone, as indicated in figure 2, section 7. Several specimens of *Agoniatites nodiferus* were found immediately below the lower massive layer of the Cherry Valley at Engleville and at Seward, 7.5 miles southeast of the type section. These occurred in a shaly limestone layer 12 inches thick. The next lower layer proved to be the *Werneroceras* limestone. Eastward to Mineral Springs the *Werneroceras* zone remains approximately one foot beneath the base of the Cherry Valley. The intervening shales are thin-bedded, break into small blocks, and are barren. From this it appears that *Agoniatites nodiferus* (Hall) is confined to a lens of shale a short interval below the base of the Cherry Valley in the vicinity of the type section. This lens disappears a few miles westward and thins eastward, finally disappearing just east of Seward (fig. 2).

In order to clarify the succession of beds at the type section the author has indicated them on plate 1 and lists them below with his own thickness figures opposite those of Clarke (1901, pp. 121-122) for comparison. It may be noted that according to the limits determined and used in this report *A. nodiferus* is, strictly speaking, a Union Springs species.

Layer	Clarke	Rickard
Limestone, upper division of the Cherry Valley	7′ 2″*	20″
Shale	—	5–6″
Limestone, gray, nodular with *Ambocoelia*	16″	5–6″
Shale, with concretions (nodules)	16″	6–7″
Limestone, top of falls, lower division of the Cherry Valley	6″	19″
Shale, barren, fissile	4″	12″
Limestone, with *Agoniatites* sp.	8″	5–6″
Shale, *Agoniatites nodiferus* zone	4′ 9″**	13″
Limestone, or series of shale and limestone, *Werneroceras* zone at base	17″	17″
Heavy black shale with large concretions	6′ 5″	22″
Limestone, thin, dark	—	3″
Shale, black, thin-bedded	—	—

* Clarke evidently has made a large error here because of the fold in the Cherry Valley described by Flower (1936, p. 6).

** Should be 12″; see Flower, 1936, p. 6.

It may also be noted here that *Werneroceras plebeiforme* (Hall) has a much greater geographic range than was formerly believed. It has been found at Stockbridge by Flower, at Cherry Valley by several authors, and at East Springfield, Engleville, Seward?, Mineral Springs, and Thompson's Lake by the writer. This is a range of 80 miles east-west with no indication that it may not range farther.

On two of the specimens of *Agoniatites nodiferus* (Hall) found at Seward both sides are preserved. This is unusual for Cherry Valley ammonoids as the rate of deposition was sufficient to preserve both sides only in rare instances. Study of these has shown that the nodes which distinguish it from *A. vanuxemi* appear to alternate in position on either side of the living chamber. One specimen is unique in two ways. First, the lateral outline of the aperture is well preserved and the deep hyponomic sinus is easily discerned. Second, in addition to a series of five nodes approximately ⅓ of the distance from the umbilical shoulder to the abdominal angle, there is a sixth on the umbilical shoulder at the base of the living chamber, as shown on the original illustration of *Agoniatites nodiferus* (Hall) in Hall, 1888, *Paleontology of New York*, volume 7, plate CXXVII, figure 7. There is also a great deal of similarity between this specimen of *A. nodiferus* and *Agoniatites intermedius* Flower. *A. intermedius* is an even rarer species of *Agoniatites*, only one specimen being known. Some doubt arises as to whether *A. intermedius* is actually a separate species or merely an individual variant of *A. nodiferus*.

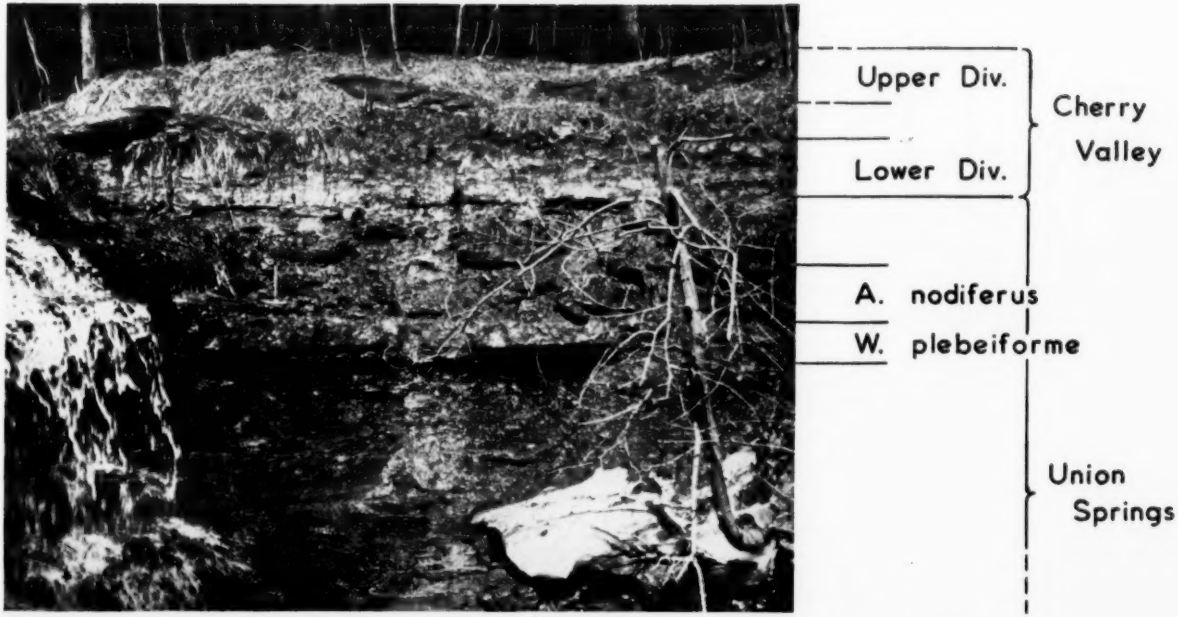
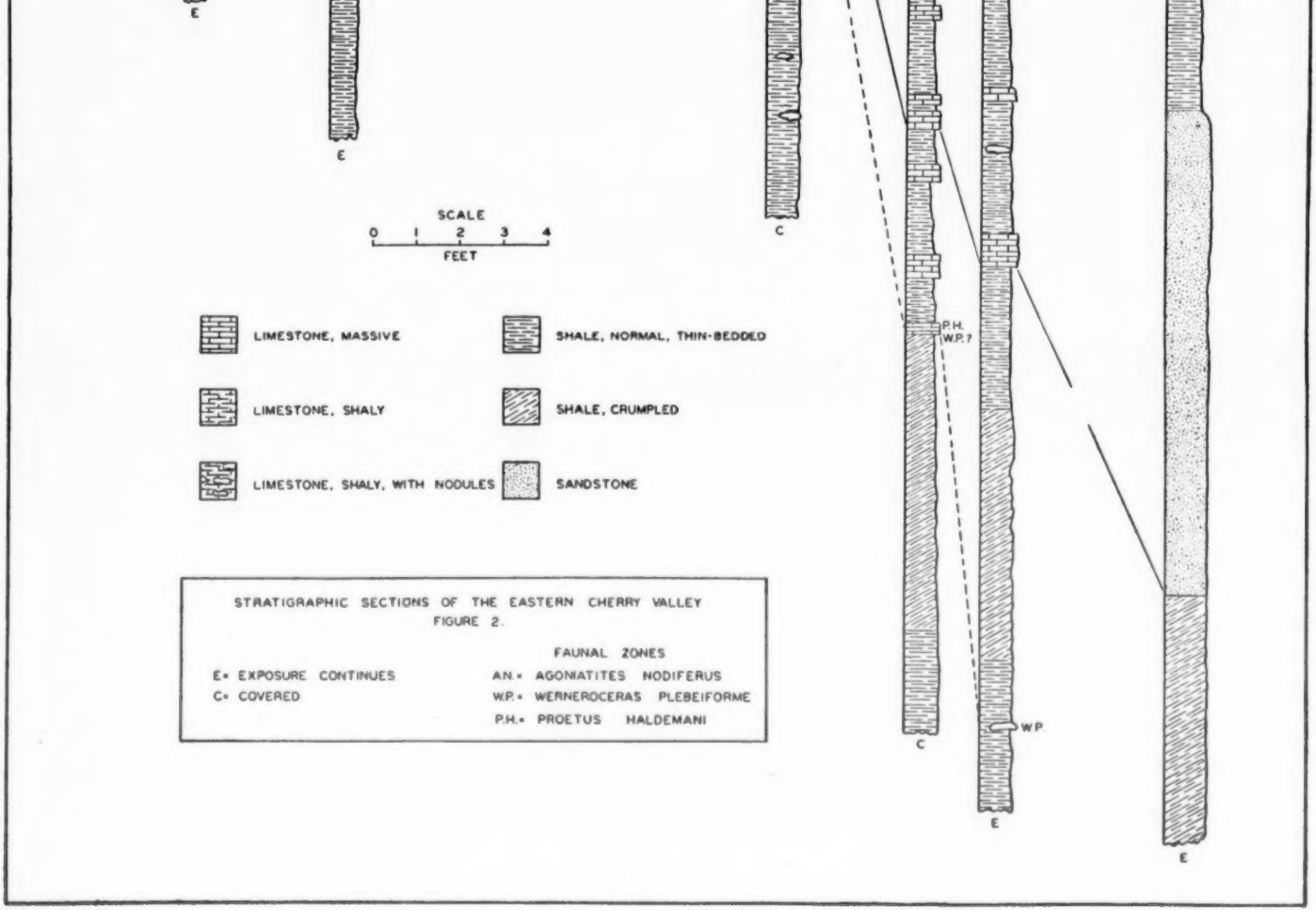


Plate 1. Type section of the Cherry Valley member, Cox's Ravine, near Cherry Valley, N. Y.



STRATIGRAPHIC SECTIONS OF THE EASTERN CHERRY VALLEY
FIGURE 2.

E- EXPOSURE CONTINUES
C- COVERED

FAUNAL ZONES
A.N.- AGONIATITES NODIFERUS
W.P.- WERNEROCERAS PLEBEIFORME
P.H.- PROETUS HALDEMANI

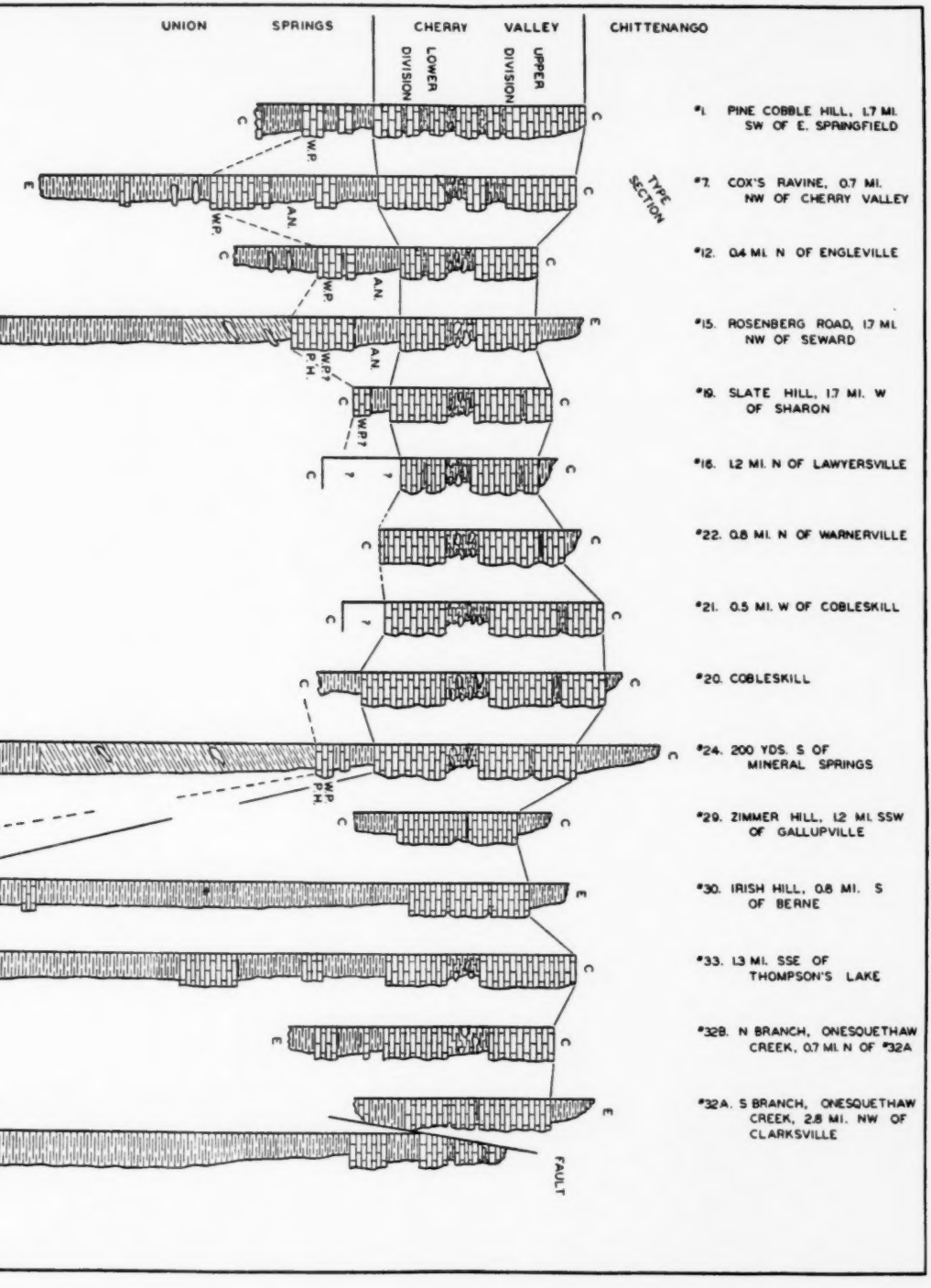

UNION SPRINGS
CHERRY VALLEY
CHITTENANGO
LOWER DIVISION
UPPER DIVISION
TYPE SECTION
W.P.
A.N.
P.H.
FAULT
#1. PINE COBBLE HILL, 1.7 MI. SW OF E. SPRINGFIELD
#7. COX'S RAVINE, 0.7 MI. NW OF CHERRY VALLEY
#12. 0.4 MI. N OF ENGLEVILLE
#15. ROSENBERG ROAD, 1.7 MI. NW OF SEWARD
#19. SLATE HILL, 1.7 MI. W OF SHARON
#16. 1.2 MI. N OF LAWYERSVILLE
#22. 0.8 MI. N OF WARNERVILLE
#21. 0.5 MI. W OF COBLESKILL
#20. COBLESKILL
#24. 200 YDS. S OF MINERAL SPRINGS
#29. ZIMMER HILL, 1.2 MI. SSW OF GALLUPVILLE
#30. IRISH HILL, 0.8 MI. S OF BERNE
#33. 1.3 MI. SSE OF THOMPSON'S LAKE
#32B. N BRANCH, ONESQUETHAW CREEK, 0.7 MI. N OF #32A
#32A. S BRANCH, ONESQUETHAW CREEK, 2.8 MI. NW OF CLARKSVILLE

Fig. 2

CONCLUSION

At the type section of the Cherry Valley limestone in Cox's Ravine, ¾ mile northwest of Cherry Valley, New York, the succession of beds exposed consists of the upper Union Springs, including the *Werneroceras* zone and, immediately above it, the *Agoniatites nodiferus* horizon, and the full thickness of the Cherry Valley limestone, the latter being 4 feet 8 inches thick. The lower contact of the Cherry Valley is drawn at the base of the massive limestone forming the brink of the waterfall. *Agoniatites nodiferus* apparently occurs only in a small, restricted lens of shale between the Cherry Valley and the *Werneroceras* zone in the vicinity of the type section. This lens disappears within 4 miles westward and extends not over 8 miles eastward. The interval between the *Werneroceras* zone and the base of the Cherry Valley is approximately one foot at all other localities excepting those in the Berne Quadrangle.

The Cherry Valley limestone extends farther east than was previously known and has been found at 19 new localities in Schoharie and Albany counties. Thus a greater opportunity exists to collect the cephalopods for which this limestone is noted. The thicknesses of several members of the Marcellus formation in the Berne Quadrangle can now be estimated as follows: Union Springs 80 to 90 feet, Cherry Valley 14 to 25 feet, "restricted" Berne 170 to 190 feet, in ascending order.

ACKNOWLEDGMENTS

The author wishes to express his appreciation and thanks to Dr. J. W. Wells of Cornell University for his advice and assistance in the preparation of this report; to Dr. R. H. Flower, formerly Assistant State Paleontologist of New York, for his identification of certain fossils and assistance in the stratigraphy; and to my father, Mr. L. R. Rickard, who has borne the expense of this work and assisted many times in the field.

All specimens of the Cherry Valley fauna found by the author are now in the collection at Cornell University, Ithaca, New York.

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[American Journal of Science, Vol. 250, July, 1952, Pp. 523-548]

RECENT SHORE-LINE CHANGES ALONG THE PACIFIC COAST OF ALASKA*

WILLIAM S. TWENHOFEL

ABSTRACT. Elevated fossil-bearing marine beaches and deltas along the Pacific Coast of Alaska indicate a general uplift of the land relative to the sea since maximum glaciation. In southeastern Alaska the relative uplift is about 500 feet, whereas elsewhere the maximum known uplift is 100 feet on the Alaska Peninsula, 60 feet in Cook Inlet, and almost 50 feet at Yakutat Bay. Present evidence is insufficient to conclude whether the shore-line uplift of the land relative to the sea was caused principally by postglacial rebound of the earth's crust as a result of deglaciation or principally by orogenic movement. A general lowering of sea level also may be involved.

INTRODUCTION

IN the course of geologic studies made in southeastern Alaska during the past several years, it has become increasingly apparent to the writer that many of the changes in the shore line along the Pacific coast of Alaska are comparatively recent. In general the changes have been uplift of the land relative to the sea since the time of maximum glaciation (fig. 1).

The writer's observations are confined entirely to the vicinity of Juneau, where he is currently engaged in a study of the mineral deposits and areal geology of the so-called Juneau gold belt. In the course of these studies many raised beaches and deltas containing marine fossils were observed. Interest in the subject of relatively recent changes in the shore line has led to a search of the literature for information on such changes elsewhere along the Pacific coast of Alaska. The writer has seen none of the localities mentioned in this paper with the exception of those in the Juneau region, and most of the basic data herein recorded are from the work of others. Essentially, this report is a compilation of published data presented for the first time under one title. As in many other problems in the science of geology, much more information is needed before the complete story of past and present shore-line changes in Alaska will be known. It is hoped that some of the readers of this paper who are doing, or will be doing, field work in Alaska will, as a result of some facts and ideas expressed herein, be on the lookout for further data bearing on this intriguing subject.

* Publication authorized by the Director, U. S. Geological Survey.

SHORE-LINE CHANGES IN SOUTHEASTERN ALASKA

Evidence of recent shore-line changes in southeastern Alaska consists of (1) raised beaches of till and gravel containing marine shells, and of (2) uplifted delta deposits.

Portland Canal

McConnell (1913, p. 22) found marine clays with admixed cobbles and boulders in the Bear River drainage just east of the Hyder district at the head of the Portland Canal. He states:

"Bluish and yellowish clays occur along Bear River above its junction with Bitter Creek, along Bear Lake, and are exposed on the sides and summit of a wide ridge 485 feet high partially blocking the valley above Bear Lake. . . . In some of the exposures, pebbles and small rounded boulders occur scattered irregularly through the mass, giving it the appearance of a boulder clay. The maximum thickness of the deposit is estimated at 155 feet.

"The principal shell locality occurs in a cutting on the Portland Canal Short Line railway above the second crossing of Bear River about 10 miles from tide water at the head of Portland Canal. The shells which consist mostly of fragments of a large barnacle, and a brachiopod, *Terebratella transversa*, both still living in the neighboring seas, are present in the clay and also occur attached to the smooth glaciated rock exposed in the cutting. They occur at elevations of from 343 to 348 feet above present mean tide.

"Blue clays holding marine shells occur along Bear Lake at an elevation of 340 feet, and similar clays without shells and interbanded with sands occur a mile farther up the valley up to an elevation of 485 feet."

Schofield and Hanson (1922, pp. 27-28) report finding stratified sands and clays at an altitude of 450 feet near Elevenmile, Alaska, on the road between Hyder and the Premier mine. They do not mention whether marine fossils were found, but from their statements it is obvious that they consider these sediments to be elevated delta deposits formed by the Salmon River when sea level was 450 feet higher. These sands and clays rest on glacial drift.

Hanson (1923, p. 40) reports clay beds on the Kitsult River and its northeast fork in British Columbia at an altitude of 450 feet. No fossils were found in these beds, but by comparison with the shell-bearing clays of Bear River, Hanson concludes that the Kitsult clay beds are marine.

The marine fossils found by McConnell conclusively indicate a postglacial relative uplift of the land of about 350 feet; and the presumed marine clays, sands, and gravels reported by Schofield and Hanson at Elevenmile, by Hanson on the Kitsult River, and by McConnell on the Bear River at altitudes of 450 to 500 feet, indicate a probable relative postglacial uplift of 450 to 500 feet for the head of the Portland Canal.

Ketchikan region

The only reported occurrence of recently uplifted marine sediments in the Ketchikan region is described by Chapin (1918, p. 99). He states:

"The most recent sediments are the glacial deposits. Rocks of this character are not abundant but have been found at one place on Gravina Island. About half a mile northwest of the cabin at the head of Dall Bay is a small exposure of glacial material about 80 feet above sea level. The outcrop is concealed on all sides by vegetation. The exposed base contains about 2 feet of glacial till and blue clay and is overlain by stratified beds of glacial gravel about 5 or 6 feet thick. Fossils occur in both the blue clays and the stratified gravel.

"A small collection of fossils from the glacial deposits was submitted to W. H. Dall, who reports:

" 'I have examined the material from Dall Bay, Gravina Island. The material is a boulder clay which disintegrates in water, and when it is strained off the fossils remain in a clean condition. . . . The species contained in Mr. Chapin's collection are as follows:

Cylichnella n. sp.
Bela violacea Mighels and Adams
Colus sp., fragment
Cardium (*Cerastoderma*) *ciliatum* Fabricius
Axinopsis viridis Dall
Macoma calcarea Gmelin
Saxicava arctica Linne
Mya intermedia Dall
Balanus sp., fragment

" 'The assembly naturally indicates the colder climate associated with the period of glaciation.'

"These fossiliferous deposits occur about 80 feet above high tide, a position that indicates an uplift of the land since the glacial epoch. Corroborative proof of a recent uplift is found in the elevated wave-cut benches found in this vicinity. That part of Gravina Island

south of Dall Head, the bold promontory that marks the south end of the highlands of the island, is a flat plain. This and similar features on Annette Island and at other places near by are regarded as wave-cut benches. Smaller features of the same character are low-lying, flat benches along the coast, some a few feet above high tide and others only partly above water. The higher benches are forested and dissected by erosion, but others near the water level are bare of vegetation and apparently have been only recently uplifted, and it is not at all unlikely that this emergence has continued to the present time. As the benches are developed only locally, however, it is probable that the uplift was of a differential character and that some parts of the region are sinking below sea level and others are rising, owing to the warping nature of the movement."

Chapin offers no evidence other than that mentioned above to substantiate the theory that the uplift was of a warping nature. Thus there is positive proof of recent relative uplift of the land of at least 80 feet in the Ketchikan region. Whether this is the maximum amount of uplift cannot be stated positively at this time. However, for reasons explained elsewhere in this paper it is probable that marine sediments are present in the Ketchikan region up to about 500 feet above sea level.

Area between Ketchikan and Juneau

Uplifted sediments containing marine shells have been reported in three places along the coast from Ketchikan to Juneau (Buddington and Chapin, 1929, p. 277). These occurrences are: (1) Goat Creek, a small stream tributary to the Stikine River about 40 miles from its mouth and about 5 miles from the international boundary in Canada, (2) in the moraine of Great Glacier on the west bank of the Stikine River above the mouth of Iskoot River, and (3) in the foundation excavation for the old cable office at Wrangell.

Buddington reports on the Goat Creek locality as follows:

"The fossiliferous beds are about half a mile up the creek at an altitude estimated at 175 to 200 feet above sea level. The beds crop out in the steep bank of the brook and consist of clay with fossil shells overlain by coarse gravel. The shells are so leached as to crumble in the fingers. A collection was submitted to W. H. Dall, who reported the following species:

Cardium ciliatum	*Leda minuta*
Pecten islandicus	*Chrysodomus liratus*
Macoma balthica	Barnacle, fragments"
Mytilus edulis	

Similar shells were found by Buddington on the moraine of Great Glacier, and he reports that marine shells were said to have been found in the town of Wrangell in the excavation for the old cable office. None of the fossils in the above localities was identified, nor was the altitude given. From maps of the two areas in question it appears that the localities are both less than 100 feet above sea level.

Uplifted marine deltaic deposits are reported by Buddington and Chapin (1929, pp. 277-278) to be common in the stretch of coast from Ketchikan to Juneau. They state:

"Uplifted gravel deposits of marine origin are found at several localities. Along the east side of Frederick Sound there is a gravel terrace from the point about 3 miles north of Point Agassiz south to and including Brown Cove. This terrace may be continuous across to Patterson River and may represent uplifted former delta deposits. Just north of Point Agassiz the coastal edge of the terrace is about 20 feet above low-tide level. At the mouth of Patterson River, Thomas Bay, there are terraces of sand and gravel at least 40 feet above the river level.

"A remnant of an uplifted delta of Stikine River forms the point at the south entrance to Le Conte Bay, extending out to Camp Island; this terrace consists of clay beds at the base and fine sand at the top. Its altitude at one point measured 60 feet above sea level. Remnants of uplifted deltas of sand and gravel are common at the mouths of many of the streams, such as Powers Creek, on Endicott Arm; Patterson River, in Thomas Bay; and Harding Creek, in Bradfield Canal."

The present state of knowledge indicates a comparatively recent uplift of the land relative to the sea of approximately 175 to 200 feet along the coast from Ketchikan to Juneau.

Juneau area

A great number of elevated deltas and marine beaches have been found in the Juneau area. Considerable geologic work, mostly related to studies of the gold deposits, has been done in the Juneau area; and in the course of these studies incidental information has been collected on the recent uplift of the land.

All the raised deltas and fossil-bearing localities known to the writer are listed below:

Fossil-bearing localities and raised deltas in the Juneau area

Location	Type of material	Altitude (feet)
¼ mile southeast of mouth of Sheep Creek at present shore line	Boulder clay and till with marine shells	35
Near head of 12th Street in Juneau on northwest bank of Gold Creek	Deltaic gravels and sands; no shells found	100
Excavation for Library, Federal Building, and large apartment building on 4th Street, Juneau	Boulder clay and till with marine shells	85
About 6,500 feet upstream from mouth of Salmon Creek on south bank a few feet above surface tram	Boulder clay and till with marine shells	375
Mouth of Salmon Creek	Deltaic gravels and sands with marine shells	100
Water pipe in town of Douglas	Boulder clay and till with marine shells	200
On trail above Treadwell glory hole	Boulder clay and till with marine shells	425
On Treadwell ditch between Paris and Bullion creeks	Boulder clay and till with marine shells	500
Below lower canyon of Lemon Creek	Deltaic gravels and sands with marine shells	60
Glacier Highway between Lemon Creek and airport	Deltaic gravels and sands with marine shells	50
Glacier Highway between Auke Bay and Indian Point	Deltaic gravels and sands with marine shells	60
Glacier Highway between Point Louisa and Point Lena	Boulder clay and till with marine shells	35
Northwest bank of McGinnis Creek, 1 mile upstream from mouth	Silt and clay with marine shells	425
Summit of divide on Amalga tramway, Eagle River	Deltaic gravels and sands with marine shells	100
Mouth of Eagle River	Sandy clay with marine shells	35

Doubtless in the Juneau area there are many other sediments of marine origin of which the writer has no knowledge; the above listing is by no means presumed to be complete. The fact that so many raised marine sediments are known in the Juneau area is probably a function of the amount of geologic study that has been done and does not indicate that the Juneau area is unique along the Pacific coast of Alaska.

W. H. Dall (1904, p. 120) collected the following fossils from an elevated beach exposed along a ditch for a water pipe in the town of Douglas at an altitude of 200 feet:

Astrangia sp. nov.
Spirorbis sp.
Serpula sp.
Balanus sp.
Leda fossa
Pecten hericeus
Astarte borealis
Venericardia stearnsii
Cardium ciliatum
Cardium decoratum
Serripes gronlandicus
Macoma balthica
Macoma calcarea
Mya truncata
Panomya ampla
Saxicava arctica
Chrysodomus liratus
Lunatia pallida
Hemithyris psittacea

The writer and F. A. Stejer collected fossils from a locality on the trail above the Treadwell glory hole on Douglas Island. The fossils were obtained from a 10-foot bank of a stream tributary to Paris Creek at an altitude of 425 feet, about 2,000 feet from the present shore line. The material containing the fossils is unstratified blue clay that contains a few scattered boulders and cobbles. Similar fossil-bearing material has been found at an elevation of 500 feet along the Treadwell ditch between Paris and Bullion creeks. The following report on the fossil collection was submitted by John B. Reeside, Jr.:

"This lot contains a number of worn valves of a species of *Cardium*, a small species of *Macoma*, a species of *Chrysodomus*, a fragment of *Mya* sp., and plates of a barnacle, *Balanus* sp. None of these are identifiable specifically . . . ."

On the Glacier Highway on the north side of Auke Bay is an elevated delta about 70 feet high from which is obtained a local supply of gravel. The writer and F. A. Stejer collected the following fossils, which were identified by Julia Gardner:

Macoma sabulosa
Macoma balthica
Mya sp.
Saxicava arctica
Lepeta (*Cryptoctenidea*) *concentrica*
Indeterminate gastropods
Barnacles

Knopf (1912, p. 33) describes three localities of marine sediments in the Eagle River region north of Juneau as follows:

"Marine deposits were found at a number of localities and are believed to have a much wider distribution, although generally concealed under a cover of moss and vegetation. Below the lower canyon of Lemon Creek, gravel banks 60 feet high are exposed, consisting of silts, well-rounded gravels, and clean sands in horizontal beds. A pebbly silt contains numerous marine shells in a fine state of preservation. The inland extension of this marine formation formed the bedrock on which rested the auriferous gravel of the lower part of Lemon Creek.

"Near the mouth of Eagle River a highly fossiliferous beach deposit was found 30 feet above extreme high tide. It rests on glacially polished bedrock, is 10 feet thick, and is fossiliferous throughout. The material of which it is composed consists of well-rounded and subangular pebbles of various rocks; some also are angular, and of these some were coated with barnacles over an inch long. The matrix in which the pebbles are embedded is a blue sandy clay, of rather solid consistence. Marine gravels were found also at an altitude of 100 feet on the summit of the divide through which the Amalga tramway passes after leaving the flats of Eagle River.

"The fossils were submitted to W. H. Dall, who reports on them as follows:

" 'They are similar to those of the boulder clay series of Douglas Island reported on by me in the reports of the Harriman Alaska Expedition. They comprise the following species, all but two of which are found living in the vicinity of Juneau:

5459. Lot 1, Lemon Creek. *Cardium decoratum* Grewingk (extinct), *Leda fossa* Baird.

5460. Lot 2, Eagle River. 100 feet above sea. *Mya truncata* L., *Saxicava arctica* L., *Cardium ciliatum* Fabr., *Macoma sabulosa* Spengler.

5461. Lot 3, Eagle River. 40 feet above sea. *Chrysodomus liratus* Martyn, *Pecten islandicus* Muller, *Cardium ciliatum* Fabr., *Venericardia gouldii* Dall, *Macoma sabulosa* Spengler, *Astarte* near *borealis* Schum, *Mya truncata* L., *Balanus* sp.' "

From the foregoing data on the Juneau region it is apparent that relative to the sea the land has risen at least 500 feet since the time of glaciation. Uplift of 500 feet for the Juneau region is similar to the 450- to 500-foot uplift indicated in the Portland Canal region. All available evidence along the coast intervening between Portland Canal and Juneau indicates a maximum uplift of but 200 feet. Two explanations for this discrepancy suggest themselves: (1) there has been differential

uplift of the coast, or (2) the evidence of a greater uplift has not been discovered in the intervening area. In view of the reconnaissance nature of the geologic studies in the area between the head of Portland Canal and Juneau it is possible that the evidence is yet to be discovered for demonstrating a maximum elevation of the land of about 500 feet for the entire coast of southeastern Alaska. In this connection it should be noted that on Vancouver Island there is evidence that the land has risen at least 400 feet since the time of glaciation (MacKenzie, 1923, p. 61).

Haines-Skagway area

Woodworth and Haight (1927, pp. 73-76), on the basis of measured differences in the height of tidal datum planes as referred to benchmark locations, have demonstrated that during the period 1890 to 1921-22 the land of the northern part of southeastern Alaska has risen a maximum of 2.53 feet. The table below summarizes their observations.

Changes in land elevation shown by plane of mean tide level

(Modified from table 33 of Woodworth and Haight, of U. S. Coast and Geodetic Survey)

Tidal station	Year of observation	Rise of land (feet)
Haines	1890; 1922	2.53
Pyramid Harbor	1890; 1922	2.37
William Henry Bay	1890; 1922	2.37
Funter Bay	1890; 1922	1.87
Mud Bay	1902; 1923	1.39
Hoonah	1901; 1923	0.96
Taku Harbor	1890; 1920	0.53
Sitka	1893; 1924; 1925	0.58
Metlakahtla	1883; 1914	0.04

Woodworth and Haight postulated that the increases listed in the above table may be attributable to the severe earthquake of September 1899 that centered in the Yakutat Bay region. At that time the maximum uplift of the land at Yakutat Bay was somewhat more than 47 feet. They realized, however, that the earthquake itself may not have been the direct cause of the rise, for they state:

"To assign the earthquake of 1899 as the immediate factor which brought about the changes in the level noted, it would have been necessary to have had tidal observations and levels made just pre-

viously to, and immediately following the disturbance. In an effort to ascertain if any subsequent changes in elevation might have occurred, the elevations of reliable benchmarks established at Hoonah and Mud Bay in 1901 and 1902 respectively, were rechecked in 1923. Here too, were found increases in elevation, amounting to 0.96 and 1.39 feet. . . . Therefore we must grant the possibility of the occurrence of earth movements and subsequent to those of 1899, which may or may not have been due indirectly to the disturbance of that year."

More recent tide observations made by the U. S. Coast and Geodetic Survey indicate that the upper Lynn Canal area is still rising and that the Yakutat earthquake probably was not the cause of the uplift. The following information was furnished by the U. S. Coast and Geodetic Survey (1950):

"Tide observations now in progress show a relative rise in land elevation at both Skagway and Haines when compared with results from earlier tide observations. The recent tide observations show that a tidal benchmark at Skagway has risen relative to sea level by about 2¼ feet since its establishment in 1908 while at Haines a tidal benchmark has risen relative to sea level by about 4 feet since its establishment in 1890. At each station an average rise in land elevation relative to sea level of between 0.06 and 0.07 feet per year is indicated for the periods covered by the observations."

Glacier Bay

On the shore of Adams Inlet, an indentation on the east side of Muir Inlet in Glacier Bay, J. F. Seitz of the U. S. Geological Survey found, in 1950, modern-appearing gastropod and pelecypod shells in clay banks about 50 feet above present high tide. These shells have not been identified. This particular locality was exposed as the Adams Glacier receded about 30 years ago and obviously the shells were buried in the clay some time prior to the last advance of the ice in Glacier Bay. The time of the last advance of ice in Glacier Bay is not known; Cooper (1937, pp. 37-62), on the basis of ring counts of trees growing on the terminal moraine of Glacier Bay, estimated the time of the most recent maximum position of the Glacier Bay ice to be in the middle 1700's, when the Bay was completely filled with ice. At present there are no reliable data to estimate the age of emplacement of the shells at Adams Inlet other than that they predate the last ice advance.

Interglacial fossil forests below present high tide have been found in Glacier Bay at several places; one locality is south of the mouth of Geikie Inlet opposite Drake Island, and another is on the north side of Bartlett Cove. These forests are a few feet below high tide and obviously indicate a submergence of the coast line since the time when the trees were alive. The age of the interglacial forests of Glacier Bay has never been determined. It is quite possible that determination of radioactive carbon content of the wood of the interglacial forest would reveal the ages of the many fossil forests so well preserved in Glacier Bay.

COASTAL REGION—CAPE SPENCER TO PRINCE WILLIAM SOUND

Lituya Bay

Uplifted benches, apparently of marine origin, are conspicuous features of Lituya Bay. They have been but briefly studied and are reported by Mertie (1933, p. 124) as follows:

"One of the most interesting physiographic features of the Lituya Bay region consists of the benches that front upon the Pacific. These are rock-cut terraces, with thin veneers of recent sand and gravel, and are developed both northwest and southeast of the entrance of the bay. The bench northwest of Lituya Bay is studded with great glacier-borne boulders for about 2 miles. Farther northwest the beach is for the most part sandy, though boulders occur at intervals. A low bench, from 10 to 15 feet high, composed largely of bedded sand, runs more or less parallel with the beach at an average distance of about 600 feet, though at places approaching close to tidewater. It is from this material that the gold placers have been concentrated by the sea. The first hard-rock terrace begins about a mile from the beach, with a sharp rise of 80 feet to a nearly flat surface about 200 feet above sea level. This bench is from 1,000 to 2,000 feet wide and at its back end rises gradually to the foothills. It runs nearly parallel with the beach and may be traced from Lituya Bay northwestward to Grand Plateau Glacier and beyond. Remnants of a still higher terrace, about 1,700 feet above sea level, may also be observed along this northwest foreland.

"East of Lituya Bay, however, other conditions prevail. For about 3 miles southeast of Harbor Point the beach has a cover of glacial boulders, similar to the beach northwest of Lituya Bay. Thence southeastward for 7 miles, to a point within 5 miles of La Pérouse Glacier, Tertiary bedrock crops out along the beach, whereas

northwest of Lituya Bay no bedrock was observed. Along this east foreland at least three well-defined hardrock terraces are visible. The first bench begins about 3 miles southeast of Lituya Bay, about 300 to 500 feet back from tidewater, and extends inland about 800 feet. The second and third benches begin about 4 miles southeast of Lituya Bay, the second 200 feet above sea level and extending back 2,000 feet, and the third about 1,000 feet above sea level and rising gradually to the hills behind."

Lituya Bay to Yakutat Bay

Few studies have been made of the coast between Lituya Bay and Yakutat Bay. This is an uninhabited and treacherous coast line, difficult of access and relatively unexplored. Blackwelder (1907, p. 86) concludes that the coastal plain has been uplifted approximately 100 feet since the time of most recent glacial retreat, but he does not elaborate or describe his evidence in detail.

Yakutat Bay

Very complete glacial and physiographic studies have been made of the Yakutat Bay region by Tarr (1909) and by Tarr and Martin (1912). In September 1899 the Yakutat Bay region was shaken by a series of earth movements that were comparable in magnitude to the most severe earthquakes the world has felt within historic times. As a result of this major earthquake the shore line of Yakutat Bay was uplifted 7 to 10 feet on the southeast side of the bay and 40 to 47 feet on the northwest side. Tarr and Martin state that the uplift took place within a period of less than four weeks and probably occurred within a single day. The uplift is ascribed by them to block faulting of the earth's crust in the vicinity of Yakutat Bay and not to a regional uplift of the Alaskan coast.

Although several trained and skillful scientific observers of physiographic phenomena have made extensive studies in the Yakutat Bay region, in only a few localities has evidence been found of shore-line changes antedating the earthquake of 1899. At the head of Russell Fiord, Tarr and Martin (1912, p. 42) found four points where trees buried in the glacial gravels are being excavated by the sea, in some places more than 3 feet below normal high tide. They were unable to determine whether the trees pre- or post-date the most recent glacier expansion.

At Logan Beach, Tarr and Martin found ancient trees, as much as 10 feet below high tide, being excavated from gravels. They found raised beaches antedating the 1899 uplift on the northeast side of Krutoi Island, just north of Logan Beach, and nearly opposite Marble Point in the northwest arm of Russell Fiord. At Krutoi Island an old wave-cut bluff is 8 to 10 feet above present sea level. North of Logan Beach an old elevated beach backed by a wave-cut gravel bluff is 5 feet above the 1899 elevated beach, or 20 feet above present sea level. In the northwest arm of Russell Fiord nearly opposite Marble Point an uplifted gravel beach backed by a wave-cut cliff in slate is about 3½ feet above the 1899 elevated beach, or about 10 feet above present sea level.

Nowhere in the Yakutat Bay region did Tarr and Martin find any signs of an uplift approaching in magnitude the uplifts in southeastern Alaska. Considering the fact that much of Tarr's and Martin's interest and observations centered about changes in the shore line, and that they report no high-level shore lines of any kind, one must conclude that either there were no such large shore-line changes as occurred in southeastern Alaska and elsewhere along the Alaska coast, or if such great changes did occur all evidence pertaining to the changes has been buried by glacial debris or removed by glacial and stream erosion. It seems most probable that the Yakutat Bay region has not undergone the uplift to which other portions of the Alaskan coast have been subjected. Before finally and conclusively accepting this conclusion it is fitting to note a word or two of caution. Tarr (1909, p. 125) records the presence in the Yakutat Bay region of extensive and conspicuous gravel deposits up to 500 feet above sea level. He believes them to be remnants of far more extensive deposits and notes that these gravels have the appearance of terraces. He rejects the possibility of the gravel terraces having been formed beneath the sea because he finds no evidence of marine life in them. However, Tarr does believe some of the gravel terraces were formed in lakes created by ice damming, but he is somewhat vague as to the details of the supposed lakes. Although Tarr largely rejects a marine origin for the extensive gravel deposits, the possibility still exists that they may be of marine origin; the lack of marine life in the gravels may be explained by the rapid deposition of gravel and sand that did not permit the

establishment of marine life. The extensive gravel deposits ascribed by Tarr to accumulation along the shores of an ice-dammed lake are best developed up to an altitude of 150 feet in the south arm of Russell Fiord.

It is of interest to note in passing that Russell (1891, pp. 131 and 167-185) collected at Pinnacle Pass near Yakutat Bay about 5,000 feet above sea level, fossil shells and leaves of plants belonging to species still living. This collection was inferred to be of Pleistocene age and was used by some writers to indicate post-Pleistocene uplift of at least 5,000 feet at Yakutat Bay. However, present knowledge of the regional structure and stratigraphy of this portion of the coast refutes this interpretation, and the "Pinnacle Pass" collection is now thought to be of Pliocene age.

Yakutat district

In the Yakutat district between Cape Suckling and Icy Bay are several beach ridges along the coastal plain. The range in altitude is from a little above sea level to 200 feet at distances of one-fourth mile to 5 miles from the present coast. In a personal communication D. J. Miller of the U. S. Geological Survey states that some of these beach lines are undoubtedly due to the formation of offshore bars with consequent filling of the lagoon behind the bar, but that the higher inland terraces indicate an uplift of the land of 100 to 200 feet.

Between Poul Creek and Icy Bay at an altitude of 2,500 feet there is a prominent marine terrace formed of unconsolidated deposits on a wave-planed surface, and at an altitude of 500 to 600 feet is a less conspicuous terrace. There is no evidence of fossils as to the age of these terraces and beach ridges; they may be as old as Tertiary.

Controller Bay and Copper River delta

Uplifted marine silt and clay of Pleistocene or Recent age has been found at Wingham Island, in Controller Bay. Martin (1908, p. 46) describes the sediments as follows:

"These deposits are best exposed on the west shore of the southeast point of Wingham Island, where they outcrop in the sea cliffs for one-third of a mile. They are bounded on the east by vertical conglomerate and on the west by steeply dipping sandstone. The eroded surface of the upturned edges of these Tertiary rocks has

been cut or warped into a shallow trough in which the younger beds lie in a gentle syncline, with maximum dips of about 20°.

"The base of these beds is below tide in the center of the trough. They extend up to a maximum of about 100 feet above high tide. The lower beds are of clay and silt, containing some sand and pebbles, with glacial scratches, and have a maximum exposed thickness of about 30 feet. Abundant, but poorly preserved, marine fossils are present. The upper beds are from 30 to 50 feet thick. They consist chiefly of coarse sand, but contain several bands, each from 6 inches to 2 feet thick, composed of gravel and boulders with glacial scratches. They rest conformably upon the lower beds.

"Similar clay, with marine fossils and scratched pebbles, were seen on the east shore of Wingham Island about 2 miles north of Kayak. They were poorly exposed at this locality. Beds of this character doubtless underlie much of the alluvial flats of the region, but, although carefully searched for, were not seen at any point except on Wingham Island. It seems probable that no other part of the region has been raised from beneath the sea in recent time.

"The following report was submitted by W. H. Dall on a small collection of fossils from the west shore of the southeast point of Wingham Island:

" '(4309) Boulder clay fossils, much crushed and broken; contains *Serripes gronlandicus* and species of *Macoma, Mya* near *arenaria, Astarte* (?), *Tellina* (?), *Modiolus, Bela* and *Balanus*, too imperfect to determine specifically.' "

D. J. Miller of the U. S. Geological Survey reports in a personal communciation that he collected Foraminifera from the uplifted beach deposits described above by Martin and that they were given an age assignment of either Pliocene or Pleistocene by J. A. Cushman. Miller further reports that he has seen marine terraces of unknown age, developed in part on bedrock, on Kayak Island and around the south end of Ragged Mountain at an altitude of about 100 feet, and at the south end of the Suckling Hills at altitudes of 100 feet and 250 feet.

Borings for the Western Bridge, across Flag Point Channel of the Copper River and Northwestern Railroad encountered vegetation in the silt at depths of 20 to 40 feet below sea level (Tarr and Martin, 1914, pp. 462-463). Borings to test the supporting strength of the bottom of Bering Lake near Controller Bay encountered a layer of peat about 30 feet below sea level. The vegetation encountered at these two localities is clear proof of the sinking of the land. The age of the vegetation is not known.

The sinking of the land may be a consequence of (1) an isostatic adjustment due to the overloading of the earth's crust by sediments of the Copper River, (2) compaction of the sediments underlying the Copper River delta and Bering Lake, or (3) general subsidence of this portion of the coast. The last theory is probably most nearly correct inasmuch as in nearby Prince William Sound, where there is no large mass of sediments, there is evidence of a very recent subsidence of the land.

Summary of uplift from Cape Spencer to Copper River delta

The present accumulated evidence for Pleistocene and Recent uplift along the 350-mile stretch of coast line between Cape Spencer and the Copper River delta is meager and inconclusive. At Lituya Bay inconclusive evidence indicates an uplift of 200 feet since Tertiary time. At Yakutat Bay it has been conclusively proved that the earthquake of 1899 raised the level of the land a maximum of 47 feet, but there is no evidence to indicate a rise of the land within Pleistocene or Recent times of more than 47 feet. In fact, at Bering Lake and at the Copper River delta it is apparent that the land has recently sunk as much as 40 feet. At Controller Bay there is proof of Pleistocene or Recent uplift of about 35 feet on Wingham Island, and elsewhere near Controller Bay there are uplifted marine terraces at 100 and 250 feet, but their age is indeterminate.

The present state of knowledge is not sufficient to indicate positively the character of the shore-line changes along this portion of the Alaskan coast. This coast is one of active glaciers and of vast deposition of glacial, marine, and alluvial materials, so that evidences of former shore lines could easily be buried and thus escape detection.

PRINCE WILLIAM SOUND AND MIDDLETON ISLAND

Middleton Island, a small isolated island in the Gulf of Alaska, strikingly exhibits recent shore-line changes made evident by elevated marine terraces. The writer is indebted to D. J. Miller of the U. S. Geological Survey, who reports the following information on Middleton Island in a personal communication:

"A sequence of moderately indurated marine clastic sediments, deposited at least in part by floating ice and probably in fairly deep

water, forms the bedrock on Middleton Island. The fairly abundant (fossil) fauna, mostly Mollusca and Foraminifera, apparently favors a Pleistocene age for the sequence, but does not preclude either a Pliocene or Recent age. Other aspects — the degree of induration, the structure, and the regional setting — in my opinion practically preclude the possibility that the sequence is post-Pleistocene, and possibly favor a Pliocene rather than Pleistocene age. Gently sloping marine terraces, formed on unconsolidated beach, lagoon, and shallow marine deposits overlying wave-planed bedrock surfaces, are developed at five levels on the island. The inner margins of the four lower terraces, which are separated by wave-cut cliffs, are at altitudes of approximately 15 feet, 45 feet, 70 feet, and 90 feet. The highest terrace has a general altitude of 100 to 110 feet; erosional remnants on it, extending up to 126 feet, form the highest points on the island."

Middleton Island thus indicates a relatively recent uplift of the land relative to the sea of at least 100 feet since Pliocene time or possibly since Pleistocene time.

There is little or no evidence in Prince William Sound indicating recent emergence of the shore line. Grant and Higgins (1910, pp. 17-18) found what they interpreted to be old beach lines, 3 to 5 feet above present high tide, at Columbia Bay, especially in a small bay on the east side of and 1 mile northeast of the eastern entrance to Columbia Bay. Tarr and Martin (1914, p. 479), on the other hand, ascribe these features to the work of waves generated by large blocks of ice falling off the face of Columbia Glacier.

The latest shore-line change in Prince William Sound is one of slight submergence. Grant and Higgins (1910, pp. 17-18) found submerged forests being killed by the sea (1) on the east shore of Knight Island, (2) on the southside of Knight Island about a mile west of Point Helen, (3) in a small cove on the west side of Latouche Island three-fourths of a mile southwest of Horseshoe Bay, (4) between Sheep and Simpson Bays, and (5) on the southeast side of Port Gravina. At the last-named locality the subsidence has been at least 10 feet. Tarr and Martin (1914, p. 479) found dead trees in place and evidently killed by postglacial submergence of the land at (6) Point Countess on Flemming Island, (7) on the southeastern side of Green Island, and (8) at Graveyard Point on the northwestern side of Montague Island.

KENAI PENINSULA-COOK INLET REGION

Tuck (1933, p. 483), in describing the glaciofluvial gravel deposits above present stream beds in the Moose Pass-Hope district, says that the extensive and conspicuous benches and terraces in the district were formed at the ". . . time the sea was at a higher level than now. Benches at several different levels in the valleys and along Turnagin Arm indicate that there were several fluctuations of the sea level." Tuck does not further elaborate upon the above statement and he does not mention the magnitude of the sea-level changes.

Martin, Johnson, and Grant (1915, p. 96) describe the extensive stratified gravel terraces along the east shore of Cook Inlet and reject the possibility of their being deposited in marine waters because of the fact that they do not contain marine fossils.

D. J. Miller of the U. S. Geological Survey reports in a personal communication that wave-planed surfaces are developed on bedrock along the west shore of Cook Inlet up to an altitude of about 100 feet. No data are available on the age of these terraces.

In the vicinity of Homer, on southwestern Kenai Peninsula, is a prominent northeast-trending escarpment 1 to 2 miles back from the northwest shore of Kachemak Bay. Farrell F. Barnes, of the U. S. Geological Survey, who has made extensive geologic studies in this area, reports in a personal communication that he believes this escarpment is a raised sea cliff. He has not particularly studied this escarpment and has no direct evidence to support his belief. If this escarpment is an ancient sea cliff, then an emergence of about 500 feet is indicated, as the base of the escarpment is about 500 feet above present sea level. The age of the supposed sea cliff is not known.

In a recent report Dobrovolny and Miller (1950) describe a blue to gray marine clay exposed along Knik Arm from Point Woronzof to Eagle River, and along the coast half a mile south of the mouth of Rabbit Creek. The following species of marine fossils were collected by Miller from clay exposed on the shore of Bootlegger Cove of Knik Arm at altitudes of 20 to 25 feet above mean high tide:

Buccinum glaciale
Odostomia sp.
Nuculana fossa
Cardium ciliatum
Macoma cf. *M sabulosa*
Saxicava pholadis
Mya truncata

The above identifications were made by F. Stearns MacNeil, who reports that the assemblage is Recent or late Pleistocene and that all of the species still live in the area.

Extensive silt, sand, and gravel deposits are interfingered with the marine clays and are believed by Dobrovolny and Miller to be part of the same cycle of deposition as the marine clay, although only in part marine. They believe that Recent or late Pleistocene marine sediments in the Anchorage area extend as high as 60 feet above mean high tide and that the silts, sands, and gravels above this altitude are probably terrestrial.

KODIAK ISLAND

On the southwest coast of Kodiak Island, Maddren (1919, pp. 306-307) found elevated marine deposits resting on glacial till and overlain by glacial till at Canvas Point 1 to 2 miles north of Ayakulik Island. The marine sediments are 30 to 50 feet above present sea level. The following fossils were collected by Maddren and identified by W. H. Dall who commented that all of the species listed below are now living in the vicinity and that the assemblage is indicative of a colder climate than now prevails.

Pecten (Chlamys) islandicus
Monia macroschisma
Tellina lutea
Macoma middendorffii
Venericardia crebricostata
Venericardia (?) *paucicostata*
Venericardia crassidens
Mya intermedia
Latisipho halli
Tachyrhynchus polaris
Astarte borealis
Saxidomus giganteus
Chrysodomus sp., fragment
Boreotrophon sp., fragment
Balanus sp., fragment

ALASKA PENINSULA

There are many indications of Recent uplift of about 100 feet on the Alaska Peninsula. Atwood (1911, pp. 75-76) makes the following statement in speaking of the Alaska Peninsula:

"Alluvial sediments extend upstream in all the large valleys until they reach an elevation of about 100 feet above sea level. Distinct marine terraces too small to be indicated on the map appear along the shores of the mainland and of the islands at about 100 feet above sea level, and upon these terraces are Recent alluvial deposits. In places such deposits include glacial material that has been

worked over by the waves. The terraces indicate unquestionably that the water stood about 100 feet higher relative to the lands in very recent times, and that during that period the alluvial lands at the heads of the bays and in the large valleys were covered by marine waters."

Knappen (1929, p. 181) says of the Aniakchak district on the Alaska Peninsula:

"On the Pacific side of the peninsula exposures of Pleistocene or Recent marine sand at altitudes as great as 100 feet indicates a recent uplift of the region, but no well-marked raised cliffs, beaches, or other shore features are known. Apparently the ocean has not stood long above its present level since the Pleistocene glaciation."

GENERAL CONSIDERATIONS

It takes only a cursory inspection of the maps of Alaska to see that most, if not all, of the Pacific coast of Alaska has the characteristic features of a typical submerged coast line. To mention a few, there are drowned valleys, glacial cirques in Prince William Sound at or below sea level, and a deeply indented coast line. The general lack of well-developed sea cliffs, beaches, and other shore features attests to the recentness of the submergence. The only exception to the statement that the Alaskan Pacific coast is one of submergence is the stretch of the coast from Cape Spencer to Controller Bay. This coast is indented, but only in a few places, by drowned river valleys and is blanketed by a heavy coat of glacial and stream deposits, possibly modified by marine action. Casual examination suggests that this coast is emergent.

The over-all features mentioned above appear at first glance to be contradictory to the evidence presented that shows the shore to be emergent. But the apparent contradiction is easily understood if one postulates a shore of submergence as the over-all characteristic of the present coast and then notes that the most recent event has been that of emergence.

Elsewhere in the world, particularly the east coast of North America, Scandinavia, and the Great Lakes region, it is well established that the weight of the continental ice cap depressed the land nearly 900 feet in places. Although definite proof is lacking, it seems reasonable to suppose that during maximum glaciation of the Pacific coast of Alaska the land was depressed by the weight of glacial ice. Since glaciation the land has risen, possibly as the result of removal of the glacial ice.

The apparent uplift of the Alaskan coast may be caused by orogenic movements bearing no relation at all to previous crustal depression by glacial ice. In the Yakutat Bay area the uplift of 1899 apparently was caused by fault movements unrelated to crustal rebound after relief from the weight of ice.

Data on hand are insufficient to indicate which of the two possible theories, i.e., glacial rebound or orogenic movements, is most probable. It is well established at some places in the world that the land has risen since deglaciation and that the areas of uplift coincide with the areas of glaciation. Similarly the entire Pacific coast of Alaska was heavily glaciated during Pleistocene and Recent times. Should the glacial rebound theory be correct for Alaska one would expect that the most elevated beaches in southeastern Alaska, for example, would all be approximately at the same altitude. However, the highest beaches in southeastern Alaska have been found in the vicinity of Juneau (500 feet) and Hyder (450 feet), the two areas that have received the most-detailed geologic study. The maximum beach level (200 feet) recognized in the intervening area may indicate merely a lack of information.

On the other hand, the Pacific coast of Alaska is a region of active volcanoes, earthquakes, and young mountain ranges, all indicative of large-scale orogenic movements of a recent date. It is quite plausible that orogenic movements have played a minor, and possibly a major, role in the uplift of the land.

One other factor should be considered. This report deals with uplift of the land, whereas actually the changes may have been brought about by a lowering of the sea. It is not considered proper to discuss the causes of sea-level changes in this report. It is possible that there may have been a world-wide lowering of sea level, caused, perhaps, by the build-up of continental ice caps on Antarctica and Greenland. However, it seems most reasonable to assume that the land has changed in elevation, as the data now on hand suggest that the changes in elevation along the Pacific coast have not been uniform in amount. If sea level has been lowered there would be recorded the same maximum apparent uplift all along the coast; such is not the case.

SUMMARY

Recent shore-line changes along the Pacific coast of Alaska have been studied in detail only at Yakutat Bay—in connection

Table of fossils from Pleistocene and Recent elevated marine sediments of the Pacific Coast of Alaska

Fossil	Locality												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Astarte (?)											x		
Astarte near borealis										x			
Astarte borealis						x						x	
Axinopsis viridis			x										
Bela sp.											x		
Bela ciolacea			x										
Boreotrophon sp.												x	
Buccinum glaciale													x
Cardium sp.					x								
Cardium ciliatum			x	x		x			x	x			x
Cardium decoratum						x		x					
Caudum islandicum	x												
Chrysodomus sp.					x							x	
Chrysodomus liratus				x		x				x			
Colus sp.			x										
Cylichnella n. sp.			x										
Latisipho halli												x	
Leda fossa						x		x					
Leda minuta				x									
Leda perfunda	x												
Lepeta (Cryptoctenidea) concentrica							x						
Lunatia pallida						x							
Mactral (?)	x												
Macoma sp.					x						x		
Macoma balthica				x		x	x						
Macoma calcarea			x			x							
Macoma middendorfii												x	
Macoma sabulosa							x		x	x			x
Modiolus (?)											x		
Monia macroschisma												x	
Mya sp.					x		x						
Mya near arenaria											x		
Mya intermedia			x									x	
Mya truncata						x			x	x			x
Mytilus edulis				x									
Nucula sp.	x												
Nuculana fossa													x
Odostomia sp.													x
Panomya ampla						x							
Pecten hericeus						x							
Pecten islandicus				x						x		x	
Saxicava artica			x			x	x		x				

Table of fossils from Pleistocene and Recent elevated marine sediments of the Pacific Coast of Alaska (Cont.)

Fossil	Locality												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Saxicava pholadis													x
Saxicava giganteus												x	
Serripes gronlandicus						x					x		
Tellina (?)											x		
Tellina lutea												x	
Trachyrhynchus polaris												x	
Venericardia crassidens												x	
Venericardia crebricostata												x	
Venericardia gouldii										x			
Venericardia (?) paucicostata												x	
Venericardia stearnsii						x							
Balanus sp.			x		x	x				x	x	x	
Barnacles		x		x			x						
Astrangia n. sp.						x							
Diatoms	x												
Gastropods (indeterminate)							x						
Hemithyris psittacea						x							
Terebratella transversa		x											
Sponge spicules	x												
Serpula sp.						x							
Spirorbis sp.						x							

1. Altitude 350 feet; Open Bay, South Valdes Island, B. C.; Can. Geol. Survey, Mem. 23.
2. Altitude 342 to 348 feet; Bear Lake near Stewart, B. C.; Can. Geol. Survey, Mem. 32.
3. Altitude 80 feet; Dall Bay, Gravina Island, Alaska; U. S. Geol. Survey, Prof. Paper 120-D.
4. Altitude 175 to 200 feet; Goat Creek, tributary of Stikine River, B. C.; U. S. Geol. Survey, Bull. 800.
5. Altitude 425 feet; Douglas Island, Alaska; collected by W. S. Twenhofel and F. A. Stejer.
6. Altitude 200 feet; Douglas Island, Alaska; Harriman Alaska Expedition, vol. 4.
7. Altitude 60 feet; Auke Bay, near Juneau, Alaska; collected by W. S. Twenhofel and F. A. Stejer.
8. Altitude 60 feet; Lemon Creek, near Juneau, Alaska; U. S. Geol. Survey, Bull. 502.
9. Altitude 100 feet; Eagle River, near Juneau, Alaska; U. S. Geol. Survey, Bull. 502.
10. Altitude 40 feet; Eagle River, near Juneau, Alaska; U. S. Geol. Survey, Bull. 502.
11. Altitude not given, probably about 35 feet; 2 miles north of Kayak, Wingham Island, Controller Bay; U. S. Geol. Survey, Bull. 335.
12. Altitude 30 to 50 feet; Kodiak Island, 2 miles north of Ayakulik Island; U. S. Geol. Survey, Bull. 692-E.
13. Altitude 20 to 25 feet; Bootlegger Cove Bay, Knik Arm, near Anchorage; collected by R. D. Miller.

with studies of the earthquake of 1899 that centered in this area. Elsewhere various geologists have reported incidental observations of shore-line changes in the course of areal geology and mineral-resource studies. Many uplifted beaches and deltas are known in the vicinity of Juneau, where a considerable amount of geologic work has been done, but even there no detailed study of the uplifted marine features has been made.

Fossil-bearing marine till has been found on Douglas Island at an altitude of 500 feet. This is the highest recently uplifted marine deposit in Alaska known to the writer. At the head of Portland Canal marine fossils of Pleistocene or Recent age are found at altitudes of 343 to 348 feet and supposed marine sediments at altitudes of 450 to 500 feet. Elsewhere in southeastern Alaska marine deposits of Pleistocene or Recent age have been found at altitudes below 500 feet. Where evidence is available it indicates that the marine deposits rest on glacial till or on glaciated bedrock surfaces and consequently postdate glaciation.

The greatest reported Pleistocene or Recent uplifts along the rest of the Pacific coast of Alaska from Cape Spencer to the Aleutian Islands is along the Alaska Peninsula and at Knik Arm; at the former locality the reported uplift is about 100 feet and at the latter about 60 feet. In Prince William Sound, in Yakutat Bay, and at the Copper River delta and Bering Lake some areas have been depressed at least 40 feet.

The data on hand are insufficient to evaluate the nature of the Pleistocene and Recent shore-line changes along the Alaskan Pacific coast. It is obvious from the data presented in the preceding portion of this paper that the most recent events generally have been those of uplift of the land relative to the sea. These data suggest that the uplift has been of a differential character; that is, not all portions of the land area have risen uniformly. However, until such time as much more data are assembled it may be best to regard the above statement as only tentative.

On the basis of available data the writer is unable to ascribe a principal cause to the shore-line changes of the Alaskan Pacific coast. Orogenic movements certainly have been at least a contributing cause, if not the major cause. Uplift of the land as a result of decreased load due to deglaciation may also have been a factor; a general lowering of sea level may also have been involved.

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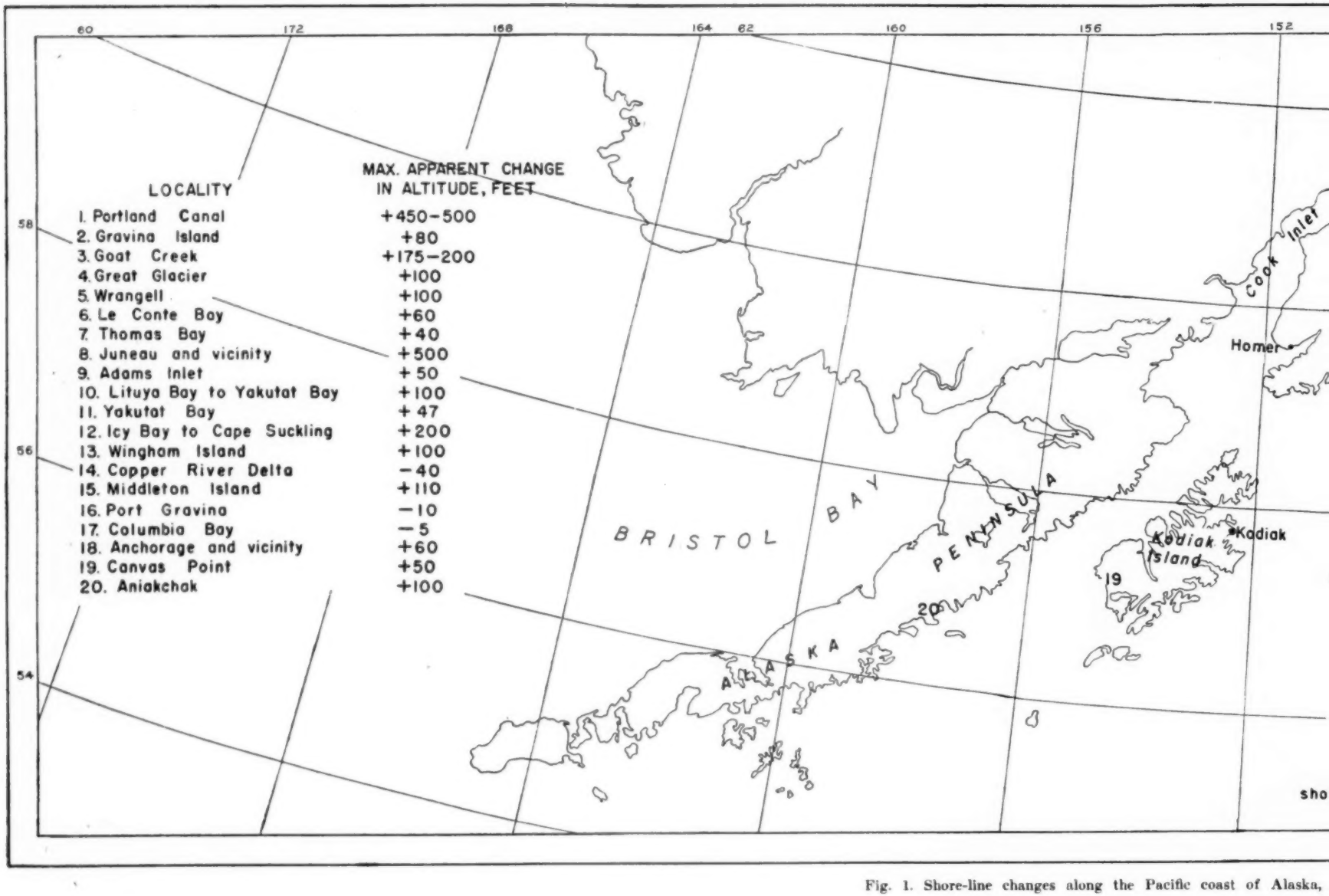
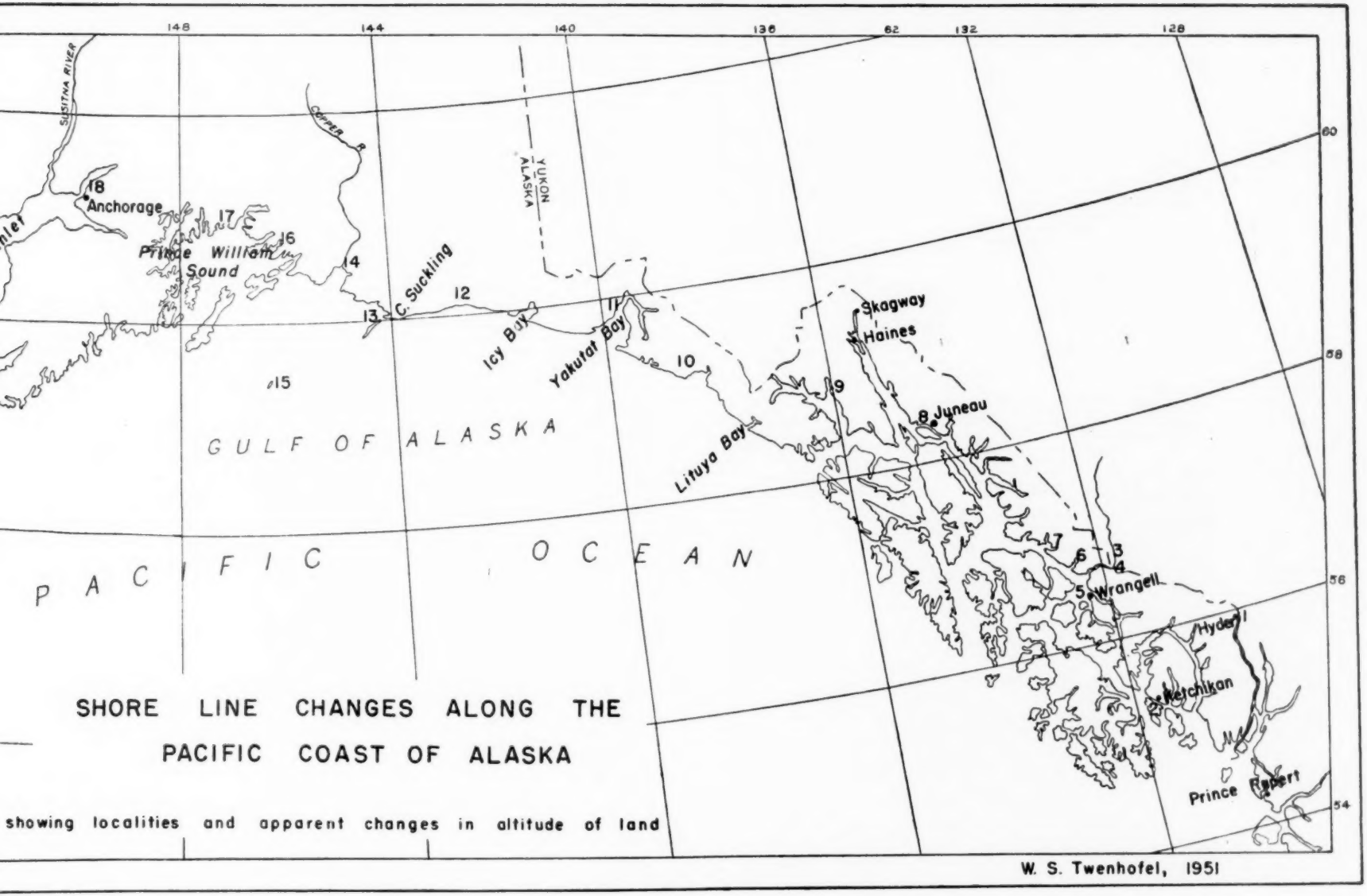


Fig. 1. Shore-line changes along the Pacific coast of Alaska,



ska, showing localities and apparent changes in altitude of land.

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Juneau, Alaska

REVIEWS

Progrès Récents de la Chromatographie, Part 1. *Chimie Organique et Biologique;* by E. LEDERER. (Actualitiés Scientifiques et Industrielles, no. 1079.) Pp. 146; 18 figs. Paris, 1949 (Hermann et Cie., 900 francs).—This volume, the first of two which are projected by Dr. Lederer, the other to deal with chromatography in the inorganic field, should be doubly welcomed in America: once for its contents and once for its author. Dr. Lederer is an expert in the field, and knows whereof he writes. In this volume Dr. Lederer has endeavored to include reference to all work done since the last review by H. Willstaedt, *Actualitiés,* no. 708 (1938), and a 32-page review of his own in 1939 in the *Soc. chim. France Bull.,* which contributes to progress in methods. Casual uses of chromatography are not all listed. The bibliography of some 538 references covers the period from 1939 to April 1, 1949; the subject index covers 18 columns. The book is written in a smooth, readable style, with clear divisions into subjects covered. After discussing new methods of chromatography, the author takes up apparatus, adsorbents, and solvents. A short chapter on chemical constitution and chromatography deals in an empirical and descriptive manner with this very interesting subject. One chapter is devoted to the chromatography of colorless substances, and this is followed by a long chapter on newer applications of chromatography. The substances discussed are grouped on the basis of their chemical nature into 17 classes. There is a good, short chapter on reactions which may occur at the surface of adsorbents used in chromatography. A two-page appendix is devoted to the life of Tswett. As long as chromatography remains in its present semi-empirical stage, those who need this method will need books, such as this one, which not only describe methods but also serve as a key to the literature, so that one may readily find what has already been done. Hints for solving one's own problems are obtainable from the work of others through this book.

HAROLD G. CASSIDY

Annual Reports on the Progress of Chemistry for 1949, *Volume* 46); issued by THE CHEMICAL SOCIETY. Pp. 333. London, 1950 (£1.5.0).—This volume is composed of 34 articles by some 20 experts. It summarizes the progress in general and physical chemistry; in crystallography for the years 1947, '48, and '49; in inorganic chemistry; in eight fields of organic chemistry including theoretical organic chemistry; in three fields of biochemistry; and in seven fields of analytical chemistry. The articles are on the whole written in a clear and lively style, an achievement which is expected of these Reports. These volumes make a great contribution to the bookshelf of the practicing chemist, and one which grows in value with time.

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South African Scenery, 2d ed., revised; by LESTER C. KING. Pp. xxxi, 379; 79 figs., 266 plates, and map in color. Edinburgh and London, 1951 (Oliver & Boyd, 45 shillings).—This is a new edition of a book first published in 1942. Quite understandably, the work is less well known to American readers than to readers in the British Empire, for it is a textbook of geomorphology, and in that aspect it is not particularly useful for American students. Like C. A. Cotton's *Geomorphology of New Zealand* (which later evolved into a textbook of international character) it deliberately draws its examples from a single great region, a subcontinent. The presentation seems designed principally for students of geography having a meager geologic background. It is primarily descriptive and its style is condensed and a bit didactic.

The book can be divided into three parts: a conventional text, a description of erosion surfaces, and a description of physiographic provinces.

The first part (chapters 1-17) follows a fairly conventional pattern, systematically discussing the processes of erosion and deposition, and the influence on them of crustal movements and volcanism.

The second part (chapter 18) presents the view that the record of at least five erosion cycles is widely represented in southern Africa: (1) A sub-Karroo surface, exhumed from beneath a cover of Karroo sedimentary rocks; (2) a "Gondwana" surface ascribed to the mid-Mesozoic, and said to be identical with the Miocene peneplane of other authors; (3) an "African" cycle which began in late Mesozoic time; (4) a "Victoria Falls" cycle which began in the Miocene; and (5) a still younger "Congo" cycle. All these cycles are ascribed to a process of "pediplanation," wherein escarpments created by valley rejuvenation retreat parallel to themselves, maintaining a constant slope, and leaving behind them ever-widening platforms of erosion. According to this view several cycles can be in simultaneous operation at the same time. This concept is not new in its essentials; it has been put forward both in Germany and in America, but it has not found favor with most American geologists. Critical discussions of it have been published (W. M. Davis, Geol. Soc. America Bull., 1932, vol. 43, p. 399; J. L. Rich, *Ibid.*, 1938, vol. 49, p. 1702). In the present work no new facts or arguments in support of this interpretation of erosion surfaces are brought forward; hence no further critical analysis of the concept seems needed. However, to this reviewer it seems a dubious policy to present to elementary students, and without accompanying factual support, a doctrine that is not widely accepted. The students are hardly aware that different views are held; in one place (p. 246) they are told in a footnote that the "Gondwana" surface, stated by the author to have been begun in mid-Mesozoic time,

is the surface erroneously referred to in literature as the Miocene peneplane. No appraisal of the relevant evidence is presented.

The third part (chapters 19-21) of the book is a morphologic analysis of the terrain of southern Africa, based upon a subdivision of the country into natural regions or physiographic provinces.

The book is illustrated with diagrams and a wealth of excellently reproduced photographs. RICHARD FOSTER FLINT

Crystal Structures; by R. W. G. WYCKOFF. Vol. II, pp. 637; First Supplement to Vol. I, pp. 136. New York, 1951 (Interscience Publishers, Inc., $10.00 and $4.00, respectively).—The first installment of Dr. Wyckoff's great compilation was copyrighted in 1948, and has been widely used and appreciated since then. It is a pleasure to congratulate the author on the completion of Volume II and of the first supplement to Volume I. A third volume is in preparation. The contents of the work to date will show its importance: Volume I, chapters I — VII: Preface, Elements, Compounds RX, RX_2, R_mX_n, $R(MX_2)_n$, $R_n(MX_3)_p$; Volume II, chapters VIII — X and XIII: Compounds $R_n(MX_4)_p$, $R_x(MX_m)_y$, hydrates and ammoniates, aliphatic compounds. Volume III is not yet availible.

The work is impressive for its size alone, but it is most remarkable for its thoroughness and for the unusual use of loose-leaf binders to permit the addition and substitution of pages from time to time. The supplementary pages for Volume I now demonstrate the value of this binding, for both additions and corrections can be inserted in their proper places. Regrettably the holes punched in the supplementary pages do not register properly with those in the original ones, so that the amended stack of sheets now in Volume I has irregular edges unless trimmed. After some preliminary study the arrangement of matter becomes easily intelligible, various criticisms to the contrary notwithstanding. It would be easy to cite advantages of other possible arrangements, especially of alternative methods of pagination; but in doing so one must not overlook corresponding disadvantages—it may be presumed that the author and the publishers have considered many alternatives and found them wanting. This reviewer favors the form used, for it permits bringing the book up to date more frequently than would be possible if whole new editions were necessary. This advantage alone far offsets the few inconveniences inherent in the present arrangement.

Critical evaluation of doubtful data is one of Wyckoff's best points. His critiques are concise and apparently adequate, and above all they are clearly distinguishable from statements made on the authority of the published works of others. There can be no doubt of the necessity for this work in every crystallographic laboratory. HORACE WINCHELL

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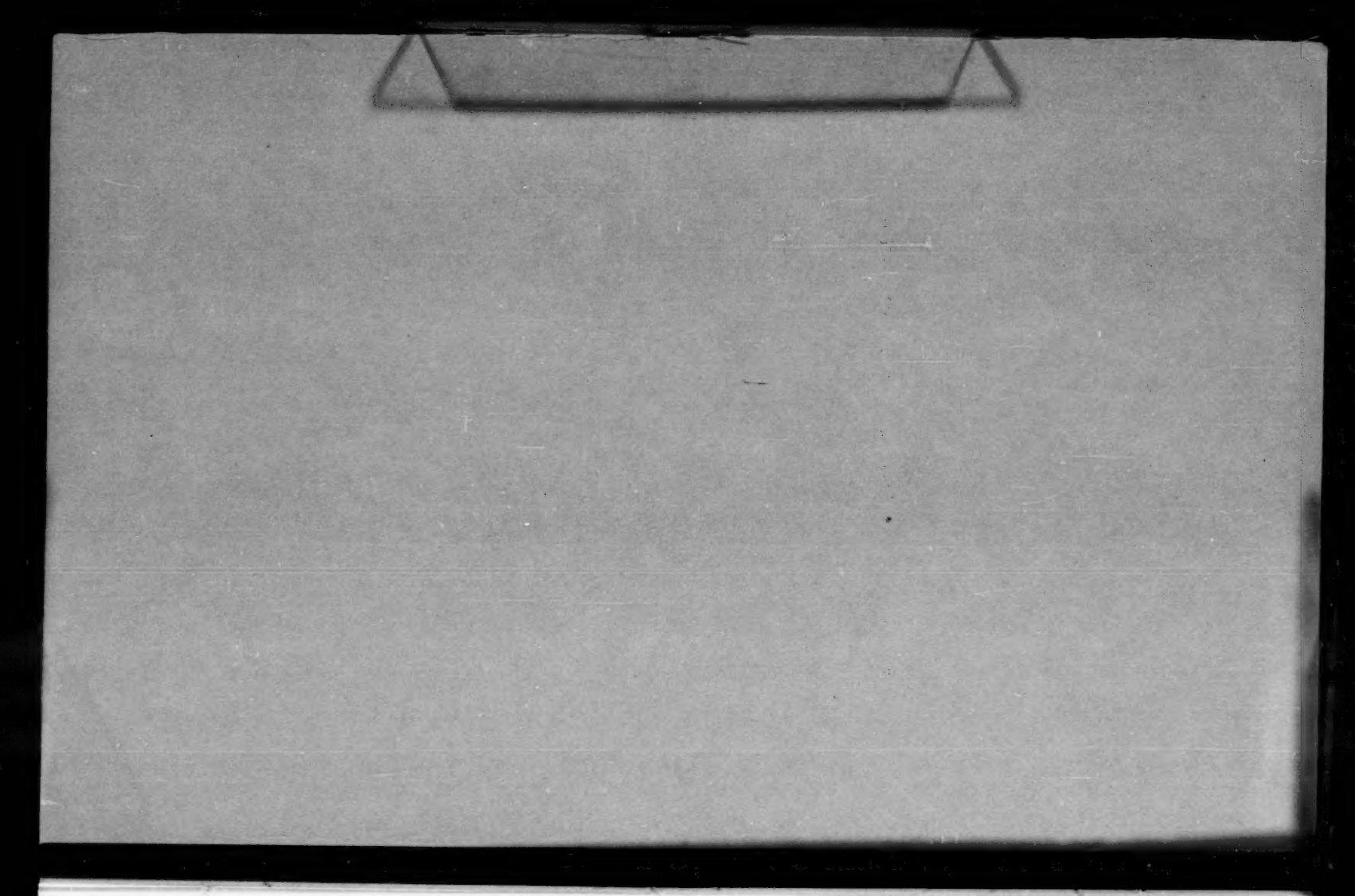

VOL. 250 No. 7, 1952

CONTENTS

SUBMARINE GEOLOGY OF TWO FLAT-TOPPED NORTHEAST PACIFIC SEAMOUNTS
Alfred J. Carsola and Robert S. Dietz 481

A STUDY OF THE TEXTURE AND COMPOSITION OF CHERT
Robert L. Folk and Charles Edward Weaver 498

THE MIDDLE DEVONIAN CHERRY VALLEY LIMESTONE OF EASTERN NEW YORK ..... *Lawrence V. Rickard* 511

RECENT SHORE-LINE CHANGES ALONG THE PACIFIC COAST OF ALASKA ..... *William S. Twenhofel* 523

REVIEWS

Progrès Récents de la Chromatographie, Part 1. Chimie Organique et Biologique; by E. LEDERER ..... *Harold G. Cassidy* 549

Annual Reports on the Progress of Chemistry for 1949 (Volume 46); issued by THE CHEMICAL SOCIETY ..... *Harold G. Cassidy* 549

South African Scenery, 2d ed; by Lester C. King ..... *Richard Foster Flint* 550

Crystal Structures, Vol. II, First Supplement to Vol. I; by R. W. G. WYCKOFF ..... *Horace Winchell* 551

PUBLICATIONS RECENTLY RECEIVED 552

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